Efficient light sources at BEUV & water window soft x-ray wavelengths

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Deirdre Kilbane, Rebekah D’Arcy, Padraig Dunne, Gerry O'Sullivan

Acknowledgments: **Thanks a million!!!**

宇都宮大学
UTSUNOMIYA UNIVERSITY

GIGAPHOTON
BEAM to the FUTURE

KOMATSU

UCD DUBLIN

sfi Science Foundation Ireland

hilase

Fraunhofer IOF

Rigaku

キヤノン財団
The Canon Foundation

東電記念財団

科研費
KAKENHI

SAMSUNG

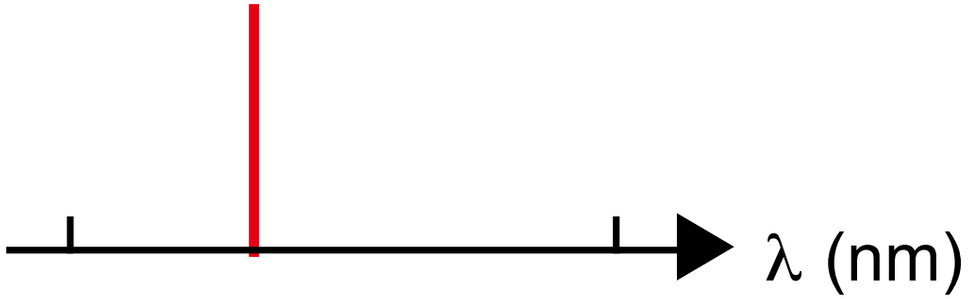
intel

Recent progress in Utsunomiya, Japan

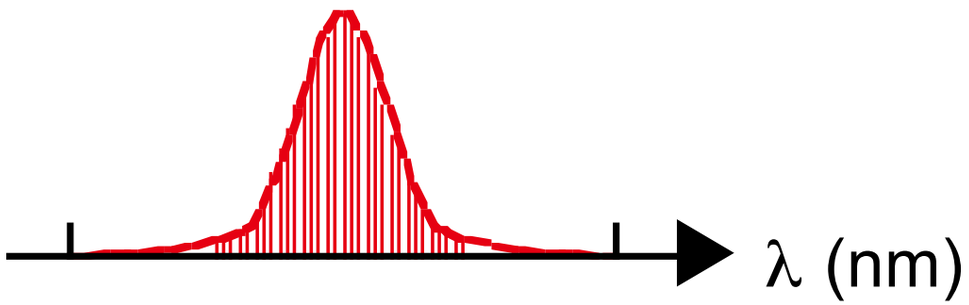
- 13.5-nm microplasma high brightness source
- simulation to evaluate plasma parameter & spectra
- seed beam at 10.6 μm for ps-CO_2 pulse
- **6.x nm & WW incoherent radiation** by various elements
- **x-ray microscope**

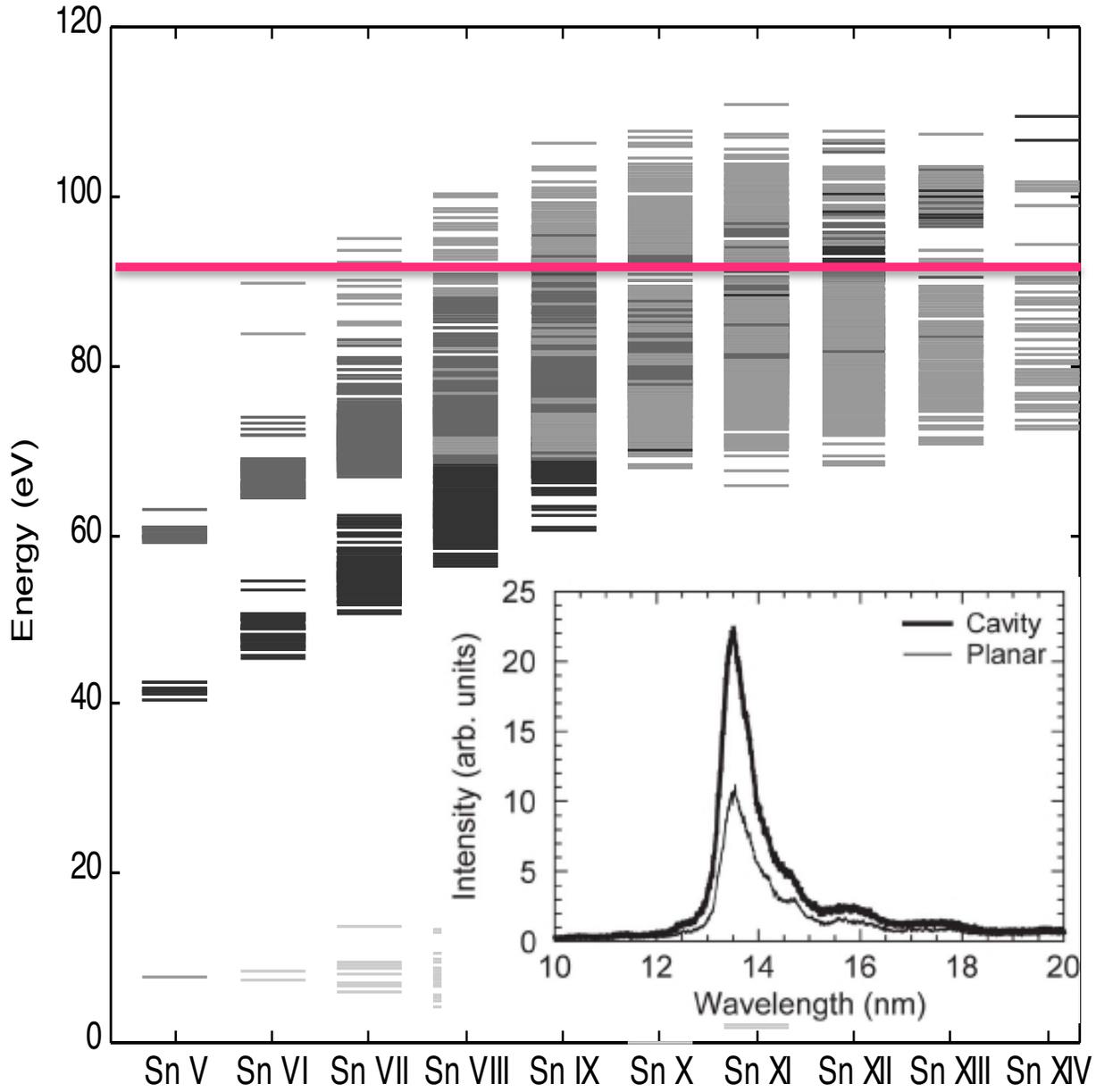
Scheme for high-energy emission: **unresolved transition array**

(a) Line spectrum



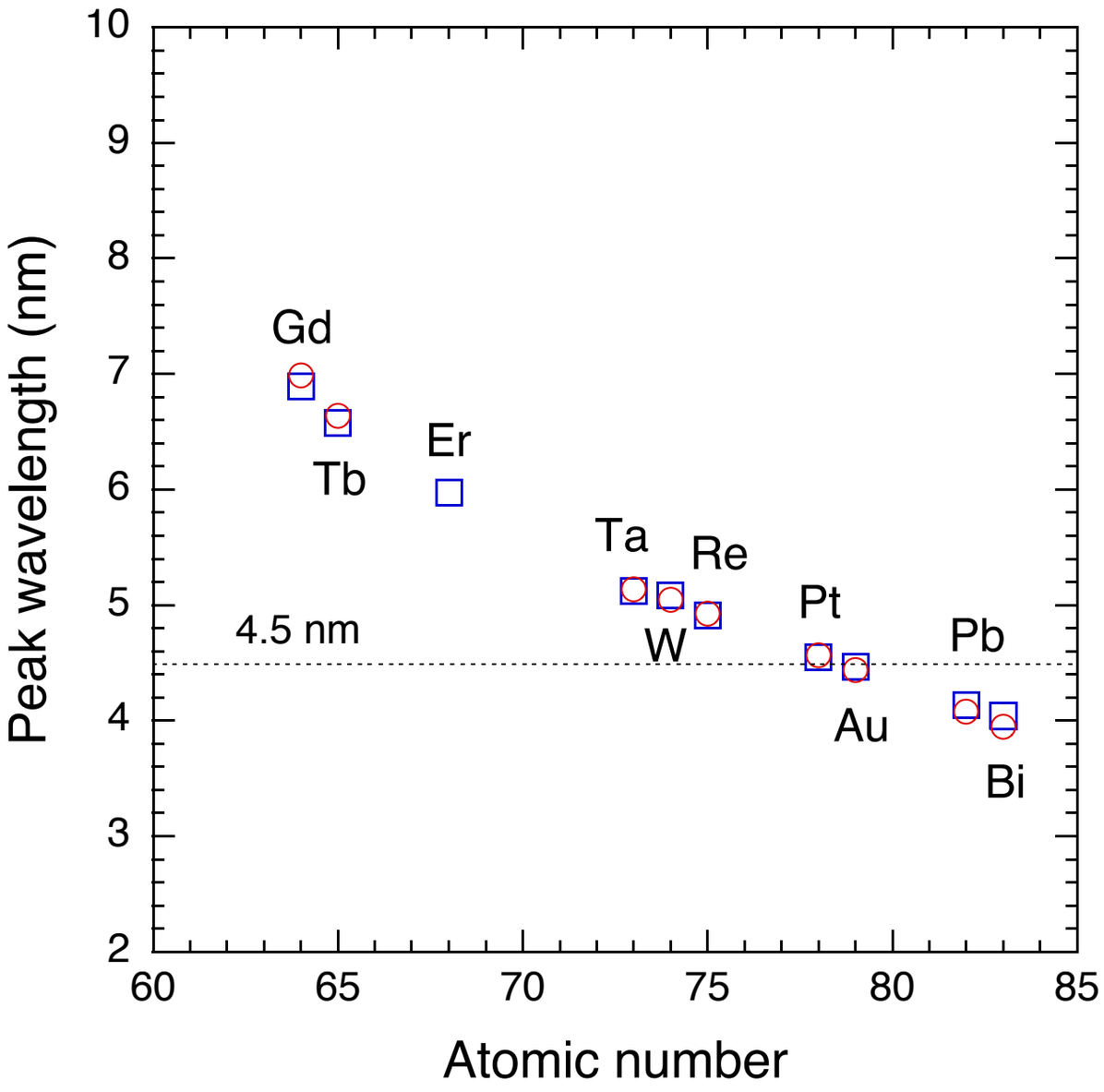
(b) UTA

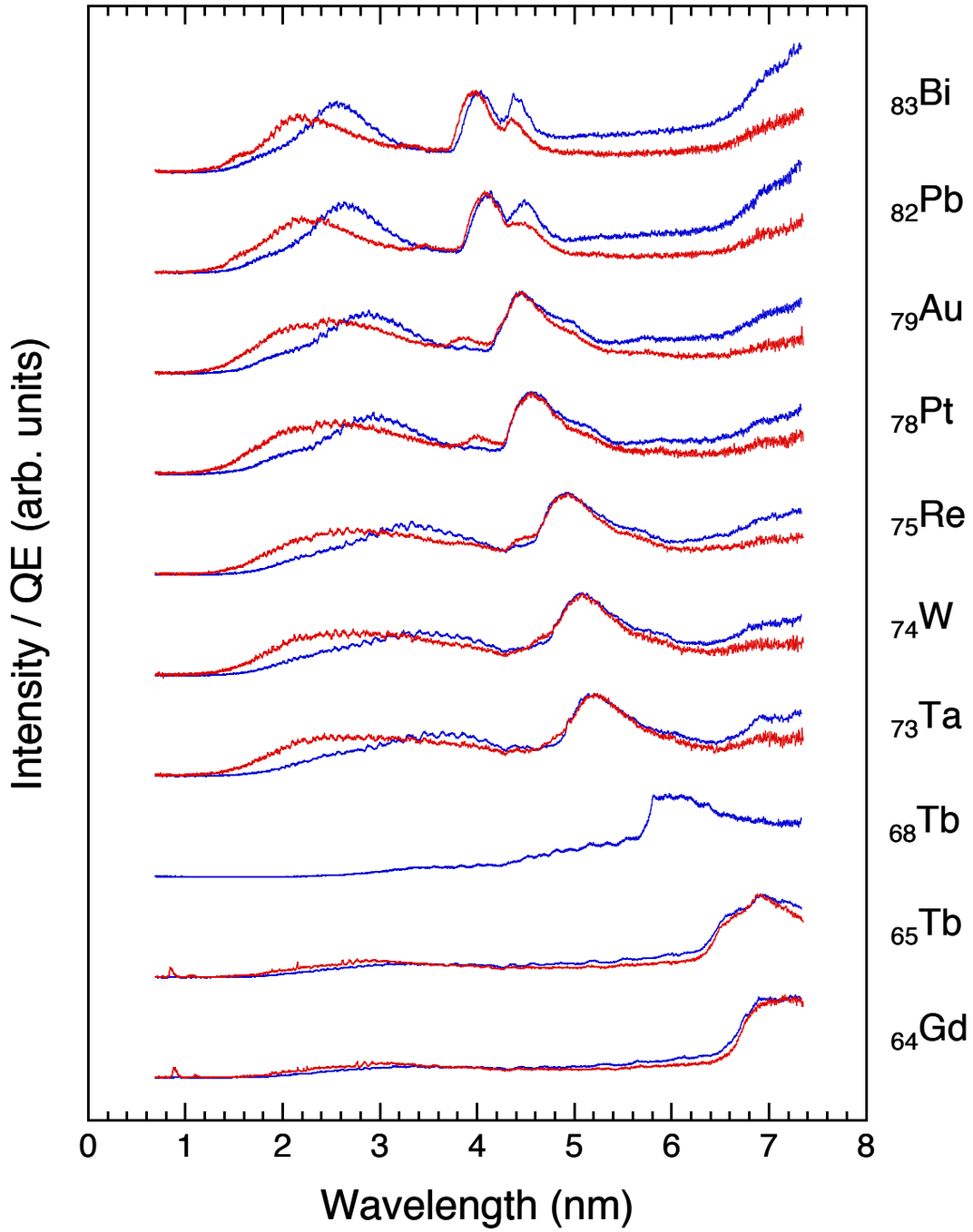




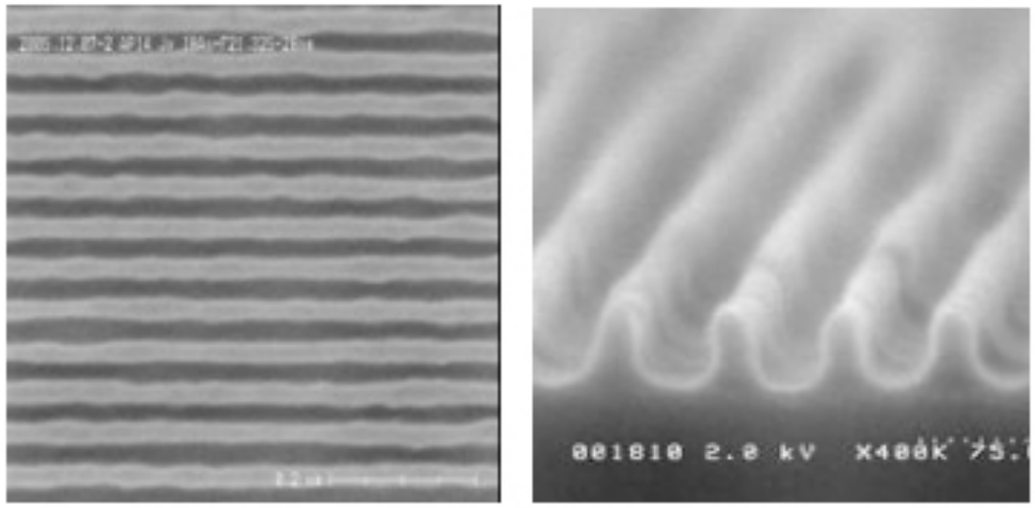
Peak wavelength of UTA emission

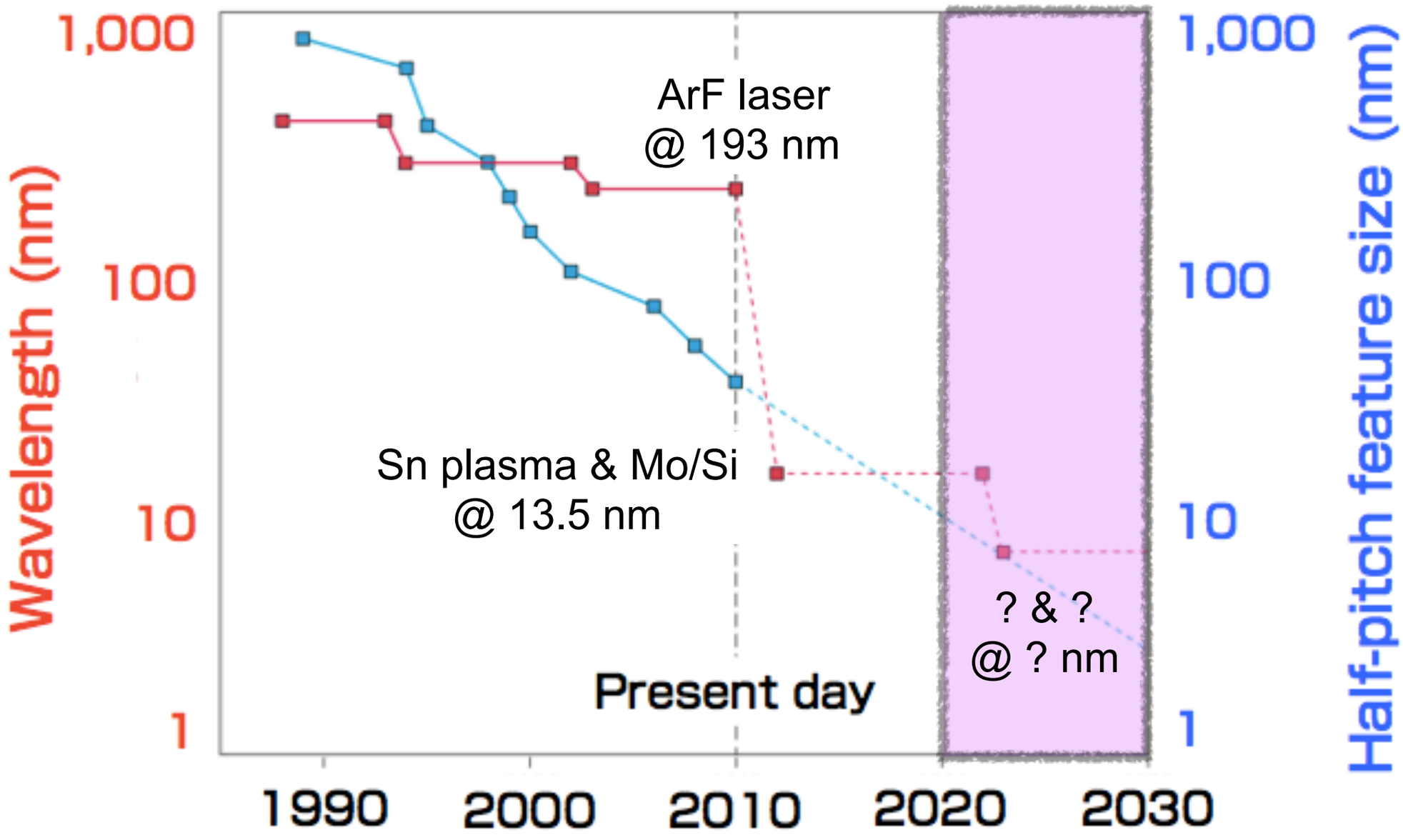
laser wavelength: 1064 nm
pulse duration: 10 ns (blue)
150 ps (red)





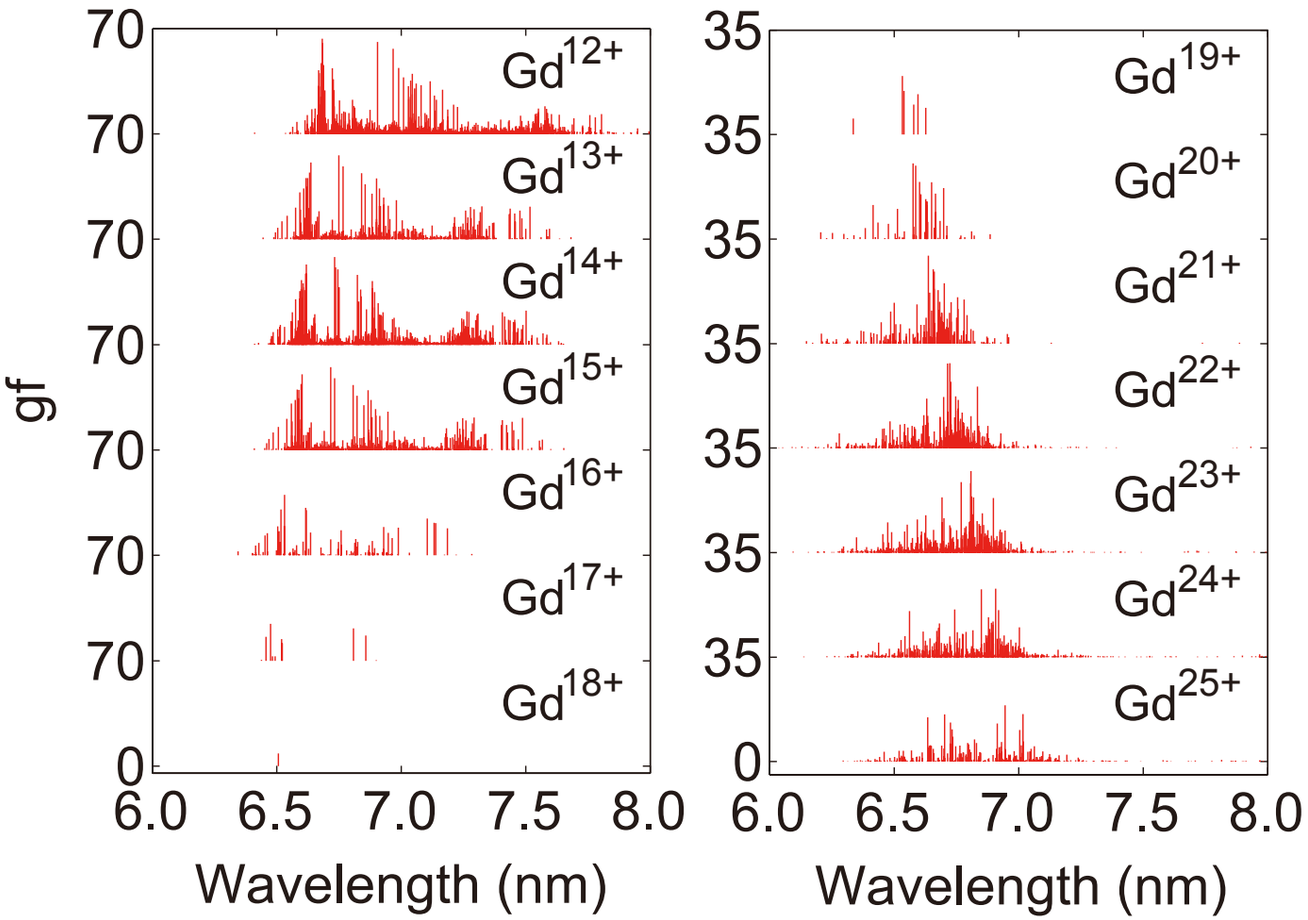
Beyond EUV at 6.x nm

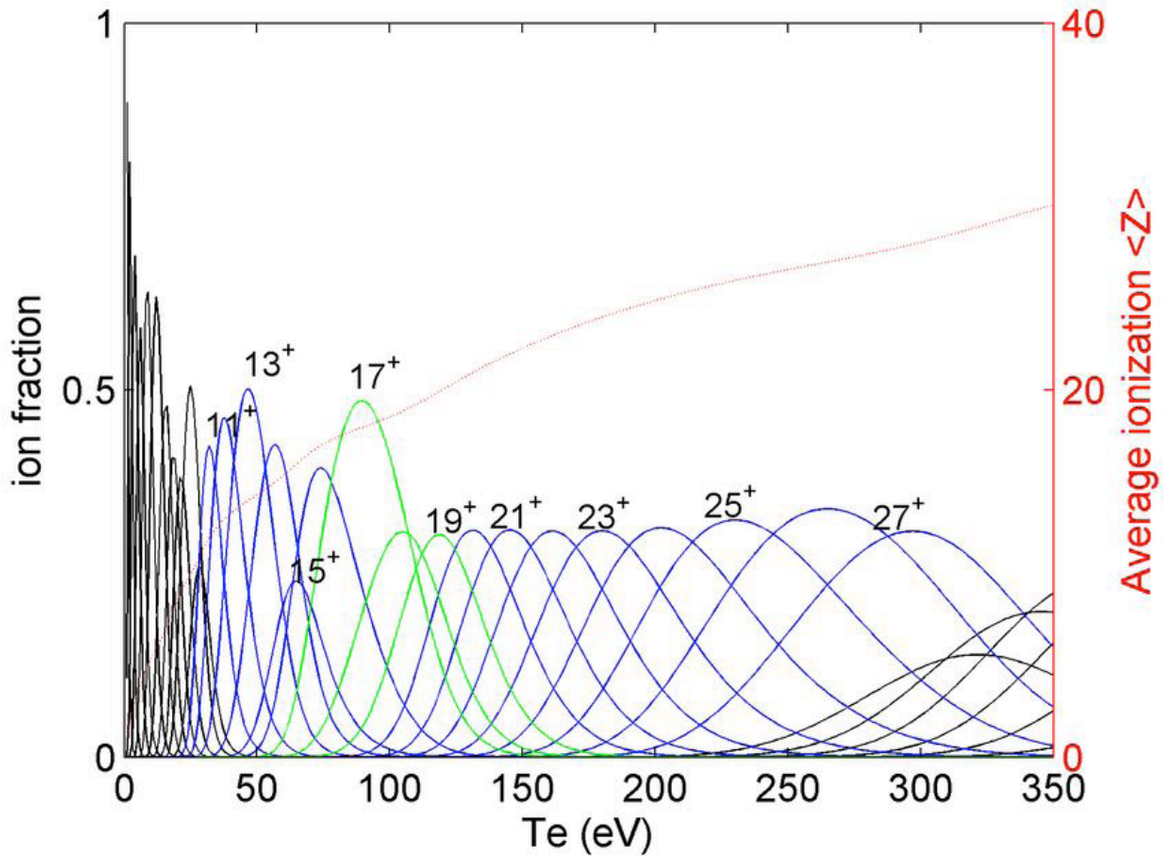




G. Tallents *et al*., Nature Photonics **4**, 809 (2010).

Rare-earth: **Gd for 6.x nm**



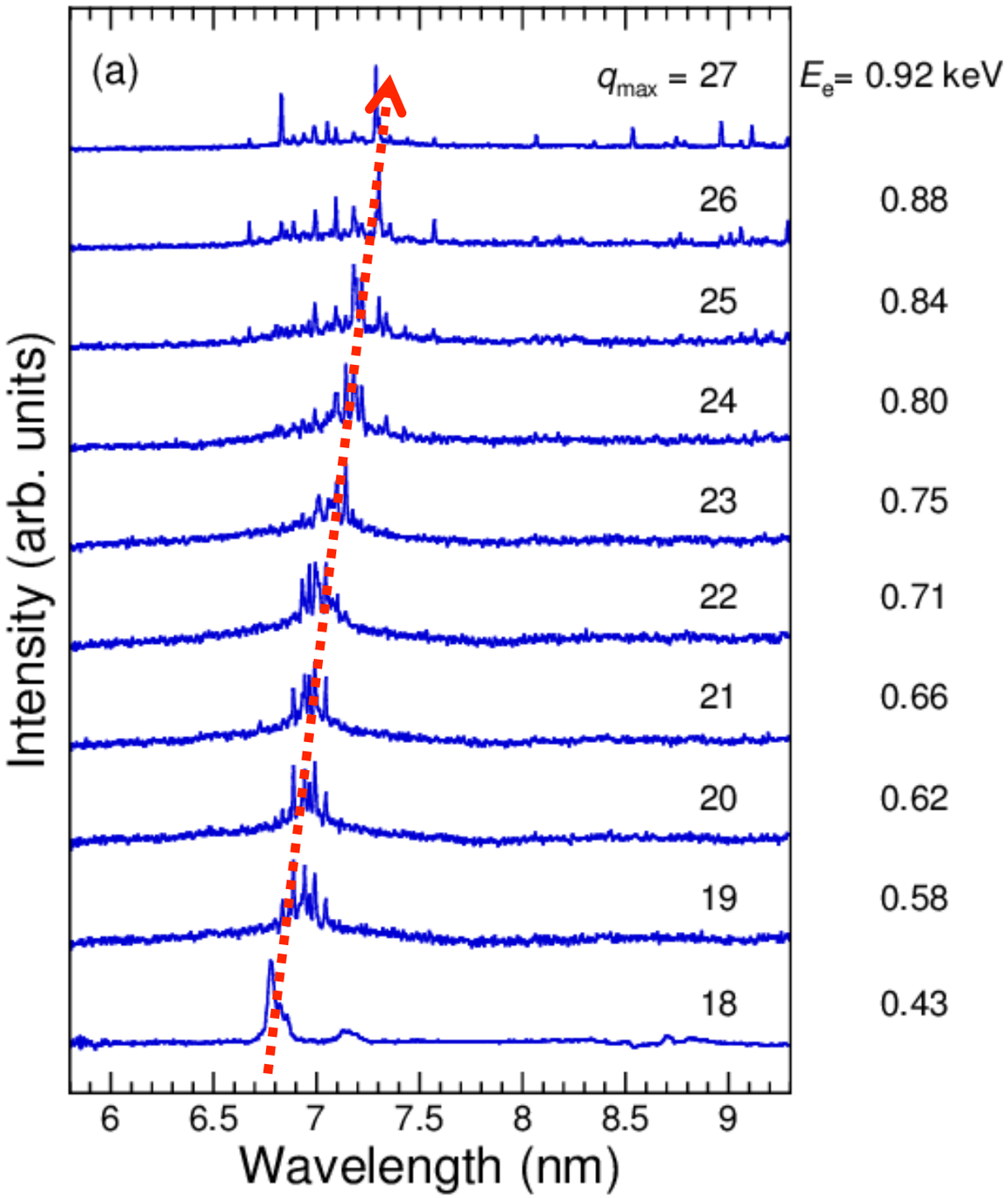


T. Otsuka *et al*., Appl. Phys. Lett. **97**, 111503 (2010).
B. Li *et al*. Appl. Phys. Lett. **99**, 231502 (2010).

Charge separated spectra **of Gd ions by E-BIT**

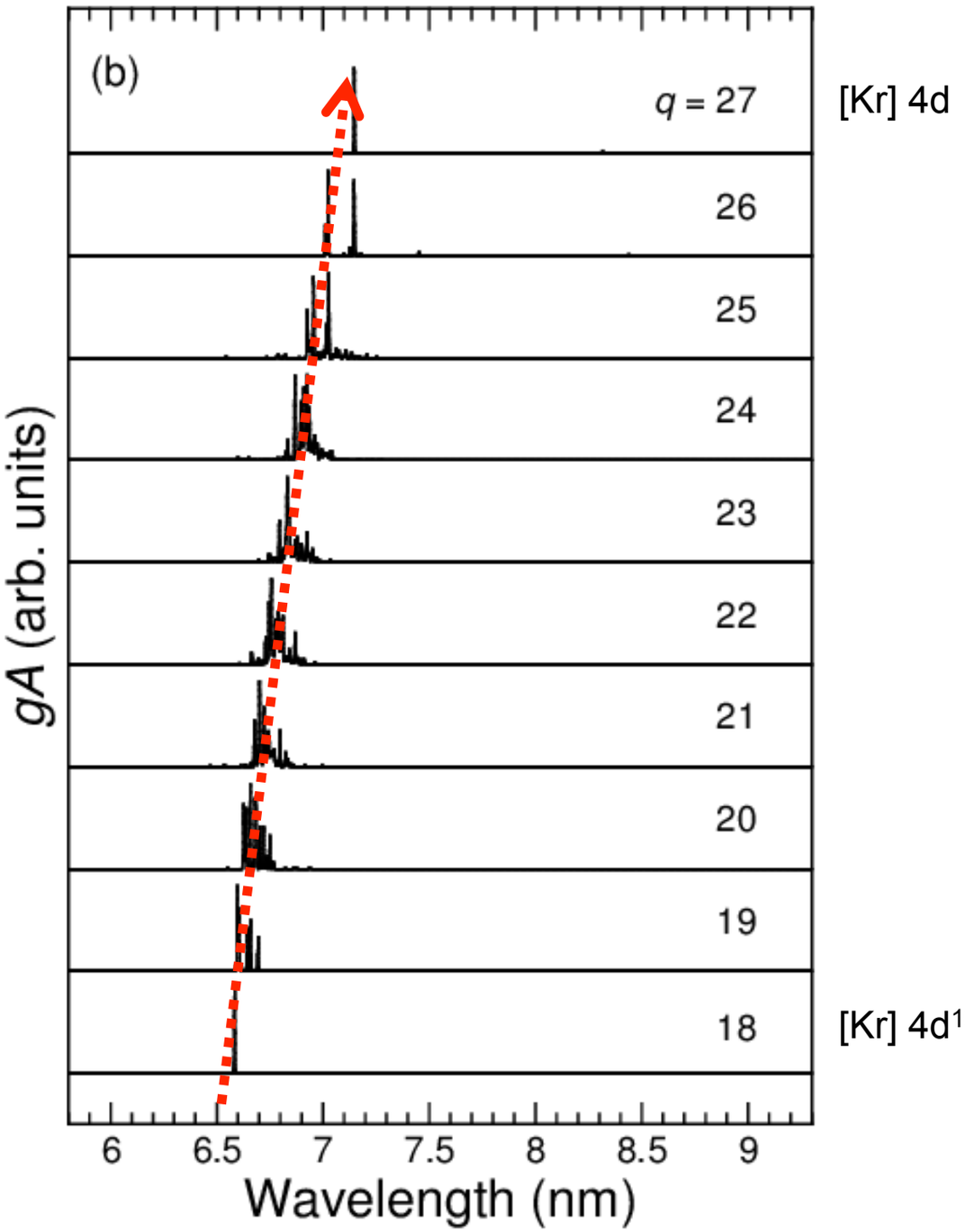
Expt.

Charge-defined emission spectra



Calc.

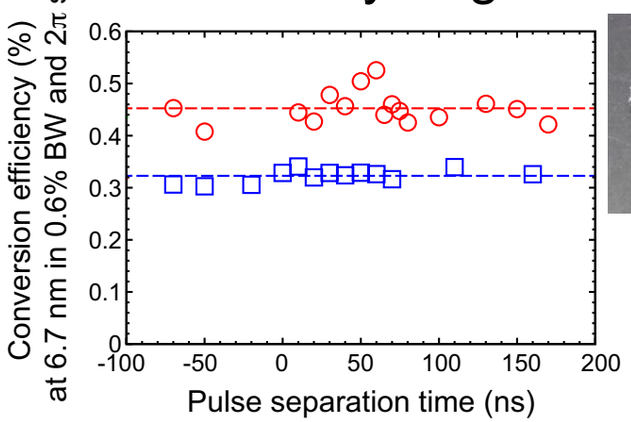
with FAC for 4d-4f transitions



H. Ohashi *et al*. (to be published)

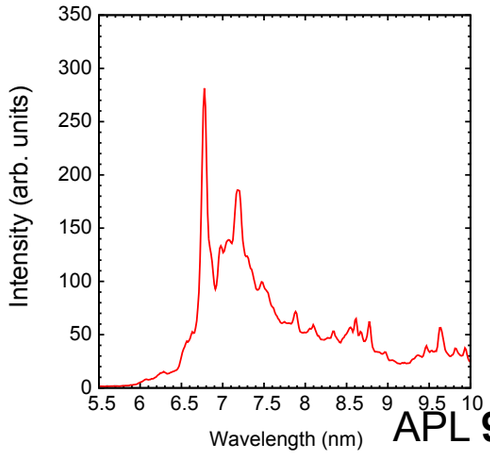
Summary in 2 years: 6.x-nm Beyond EUV sources

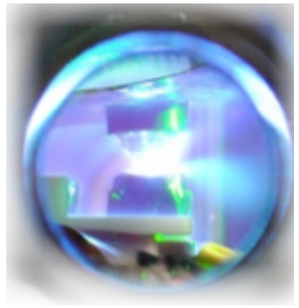
low density target



APL **99**, 191502 (2011).

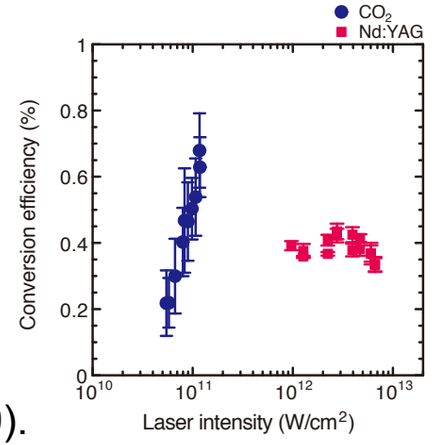
DPP

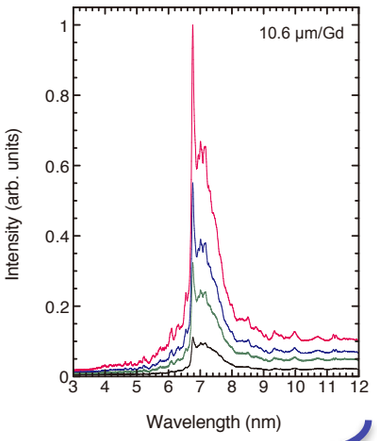




APL **99**, 231502 (2010).

CO_2 LPP



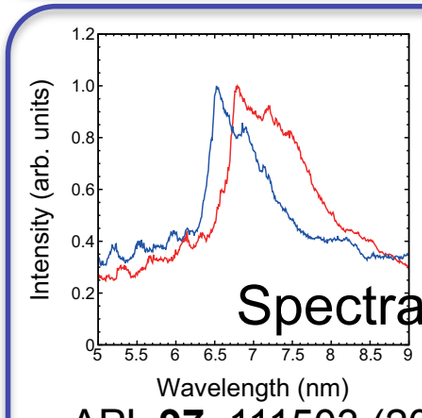


Opt. Exp. (accepted).

$$I(\lambda) = I_0(\lambda)e^{-\sigma n \ell}$$

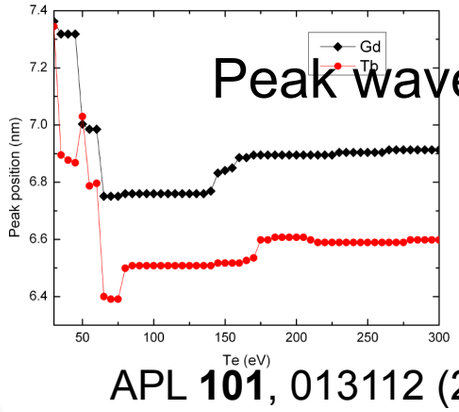
$$\ell \approx c_S \tau_L$$

Spectral structure



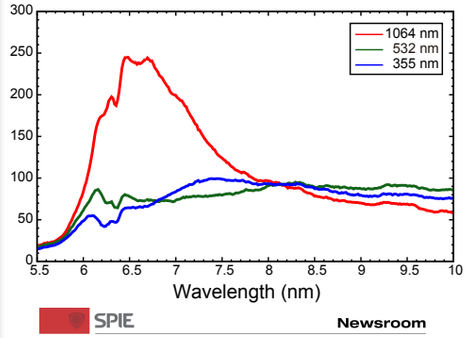
APL **97**, 111503 (2010).

Peak wavelength

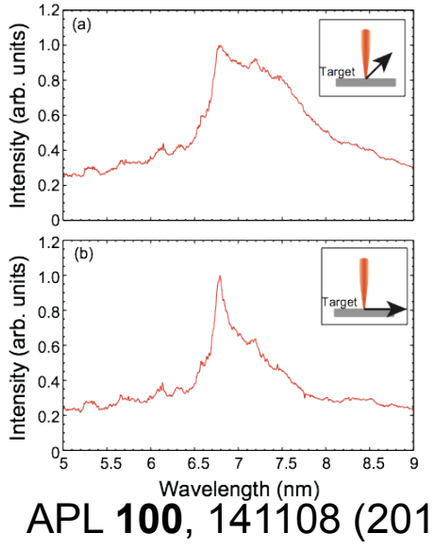


APL **101**, 013112 (2012).

Self-absorption

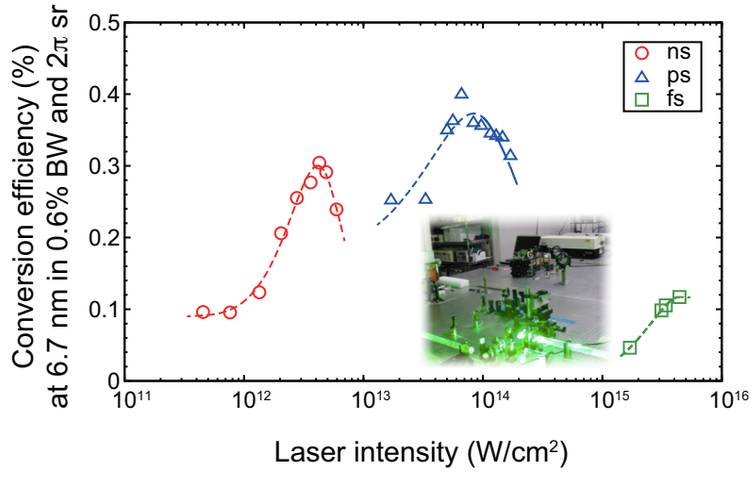


APL **97**, 231503 (2010).



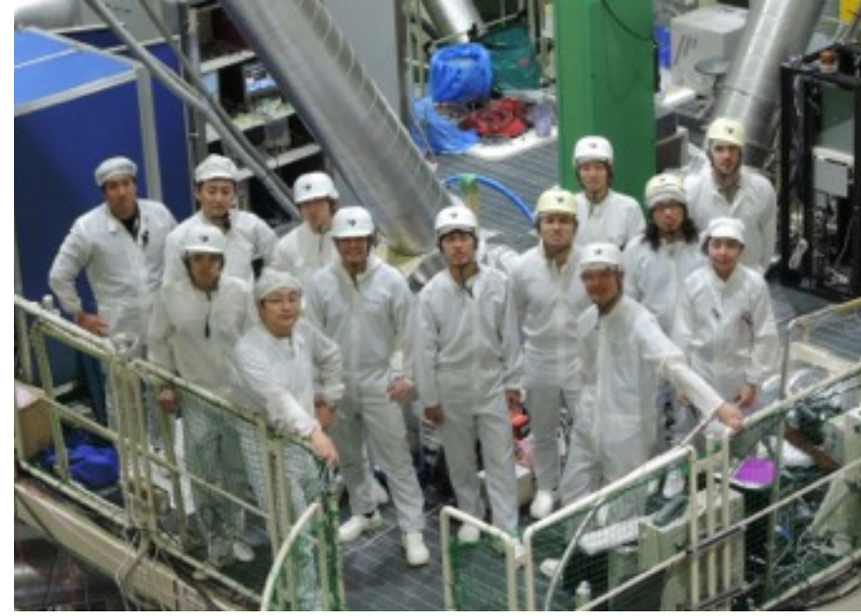
APL **100**, 141108 (2012).

ps LPP

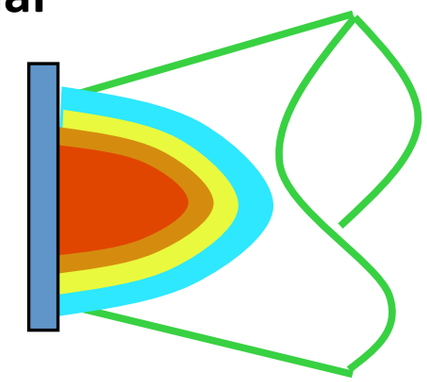


APL **100**, 061118 (2012).

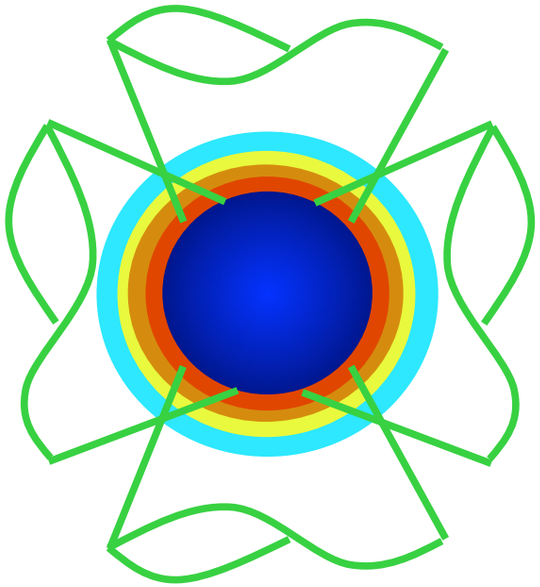
Database experiment by GEKKO XII

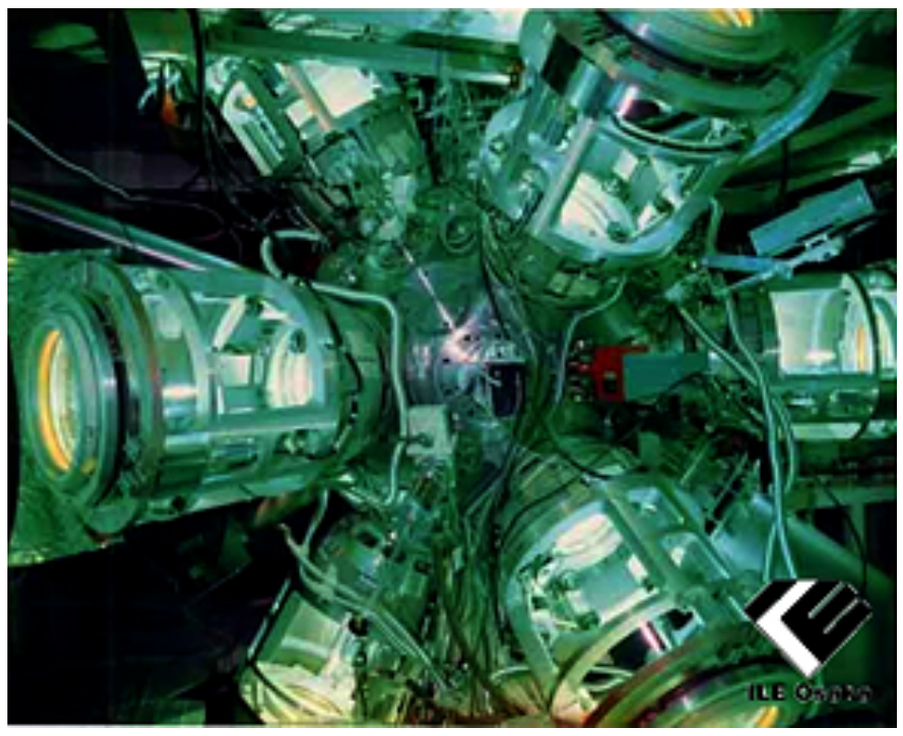


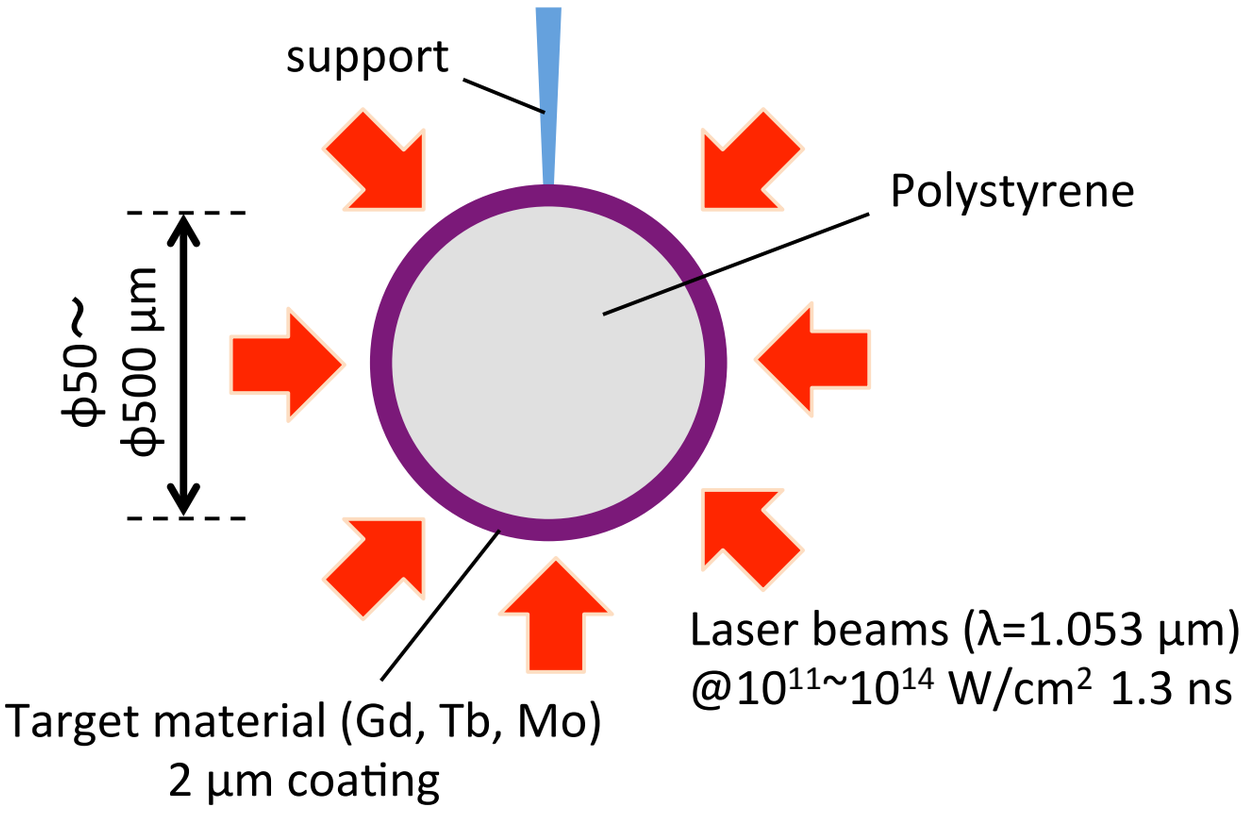
Planar



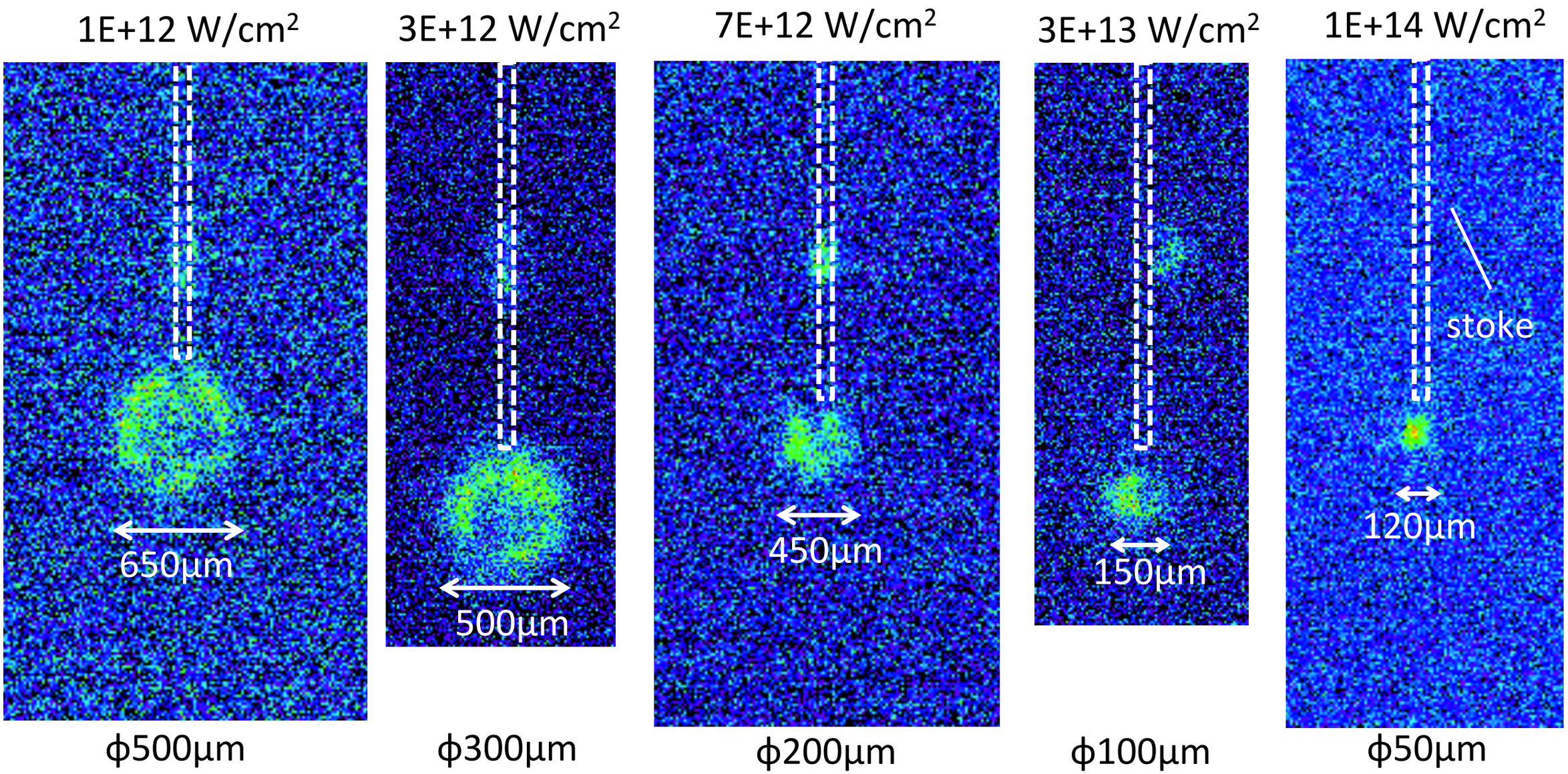
Spherical



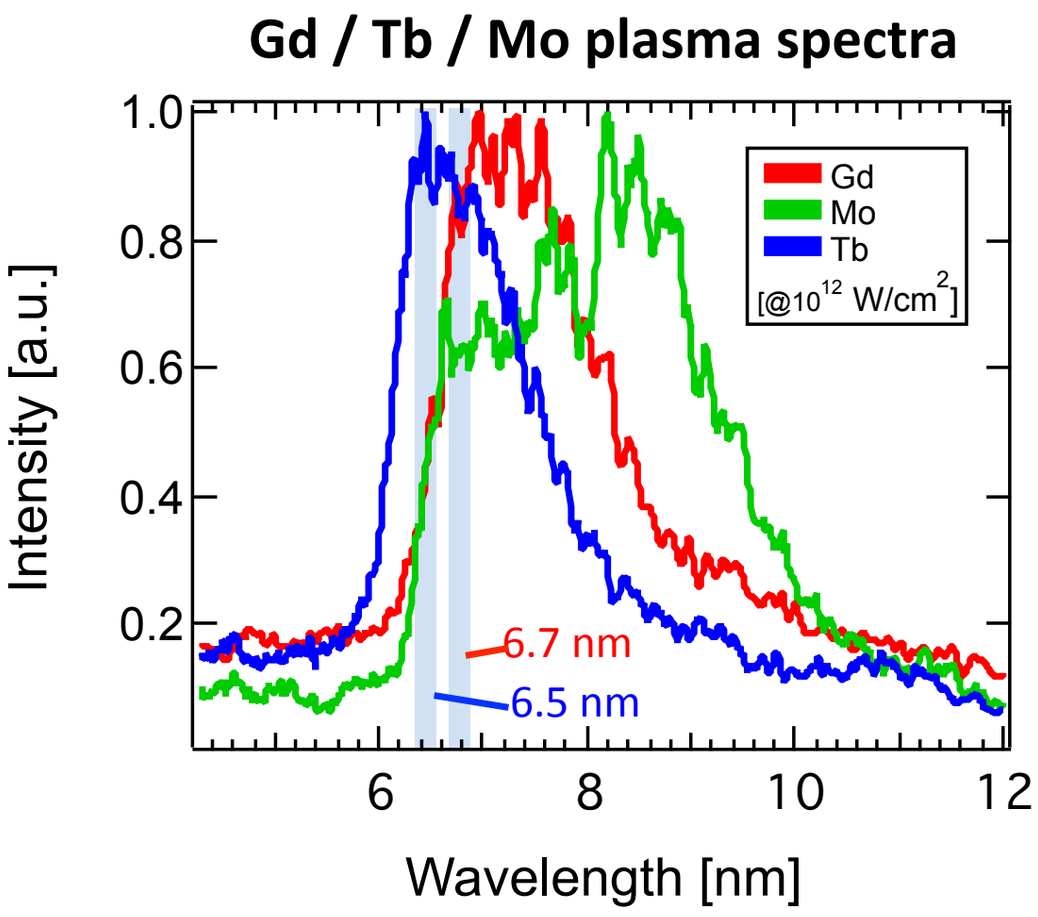


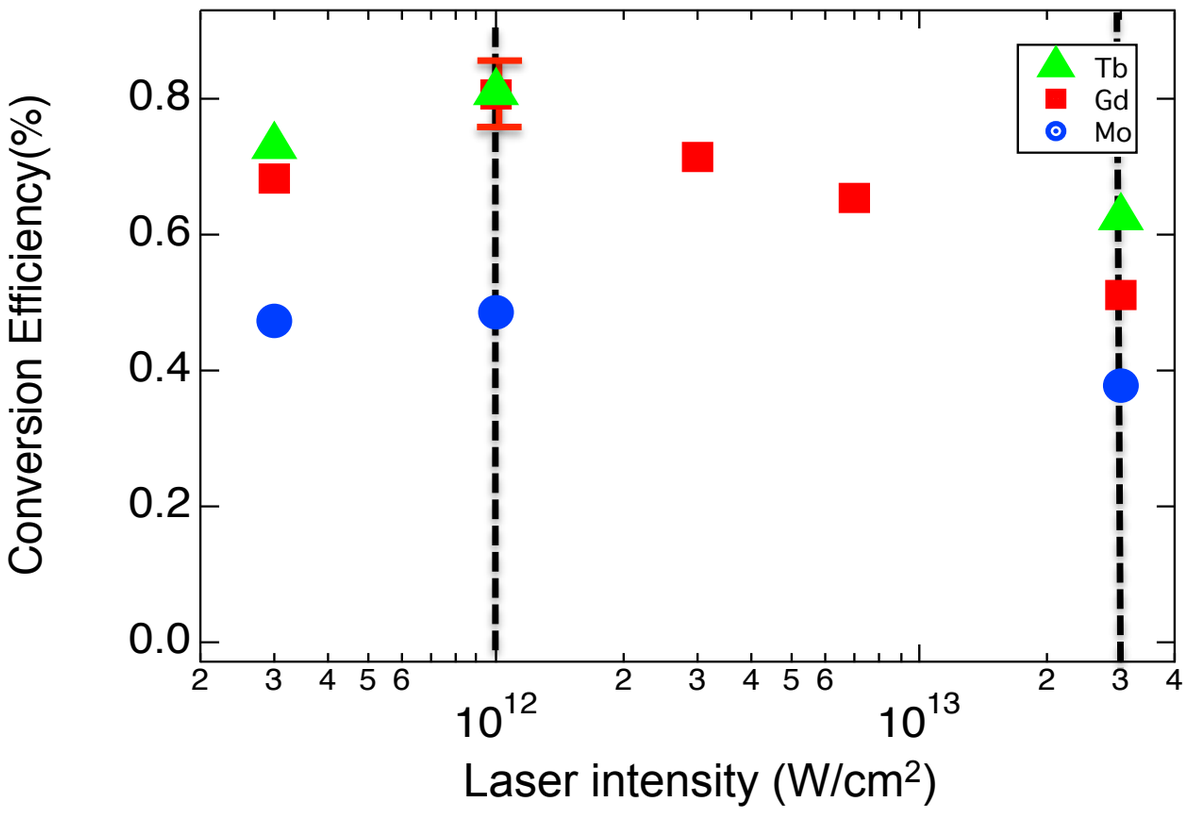


EUV pinhole camera images at 6.7 nm with 0.6%BW from Gd plasmas
(magnification: x 5.7), Zr filter + La/B_4C mirror

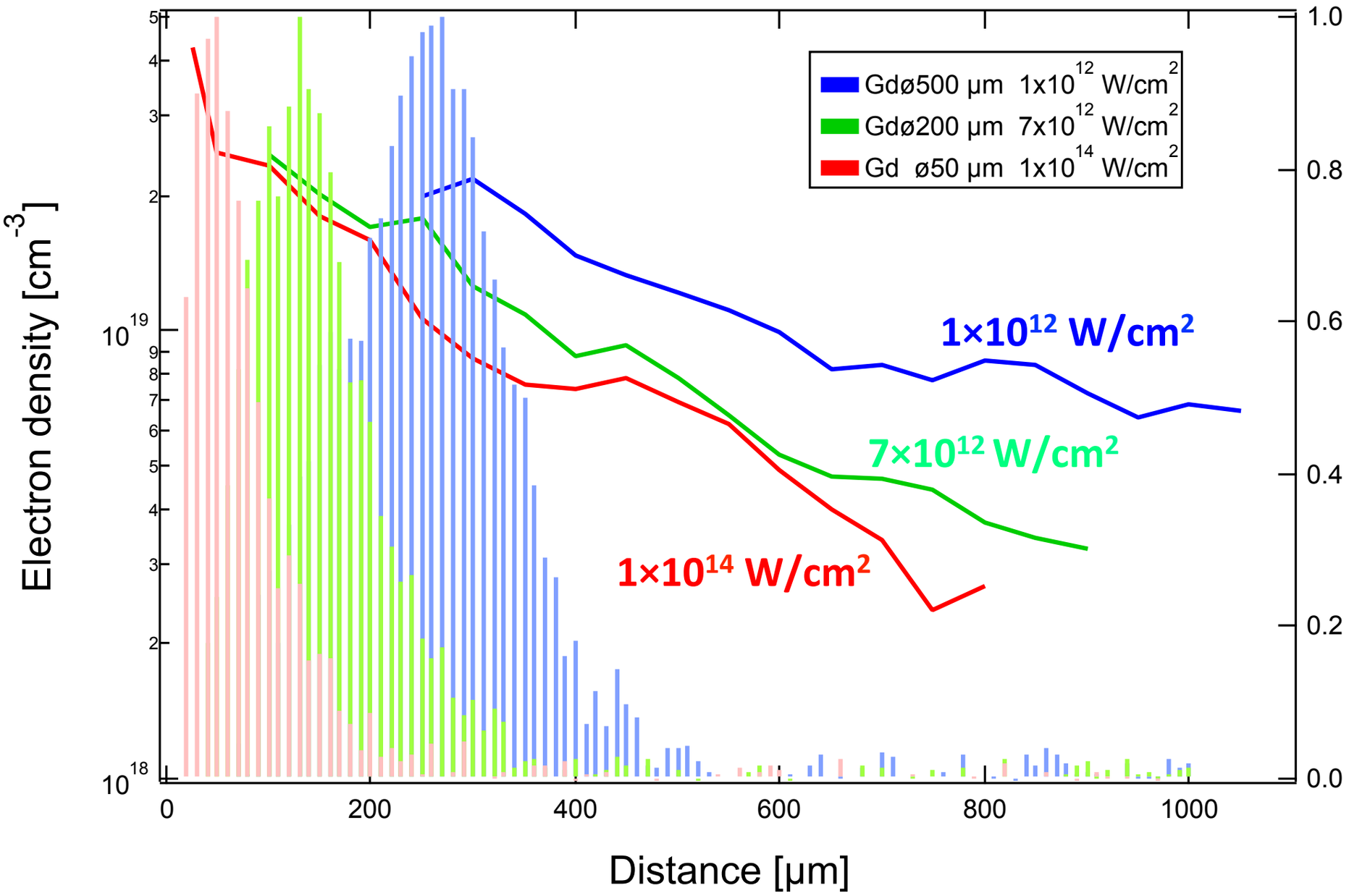


Spectra & CEs in GEKKO XII exp





Electron density profile



Requirement in high-Z plasma UTA **with high CE**

Low density, high temperature plasma

Optically thin plasmas for reducing self-absorption effects

Suppression of satellite emission & higher spectral purity

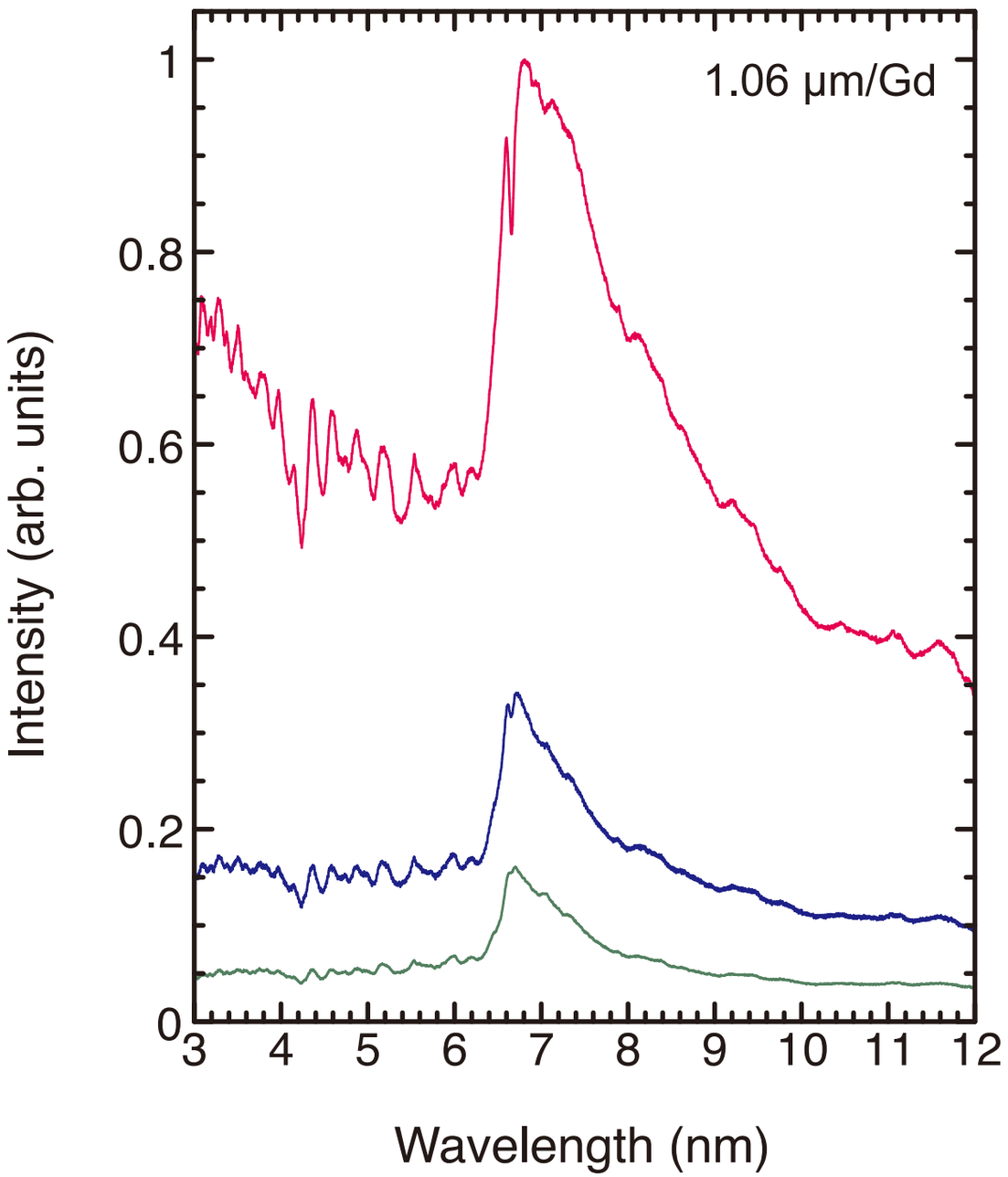
Long wavelength (low critical density): **CO_2 laser**@10^{19} /cc

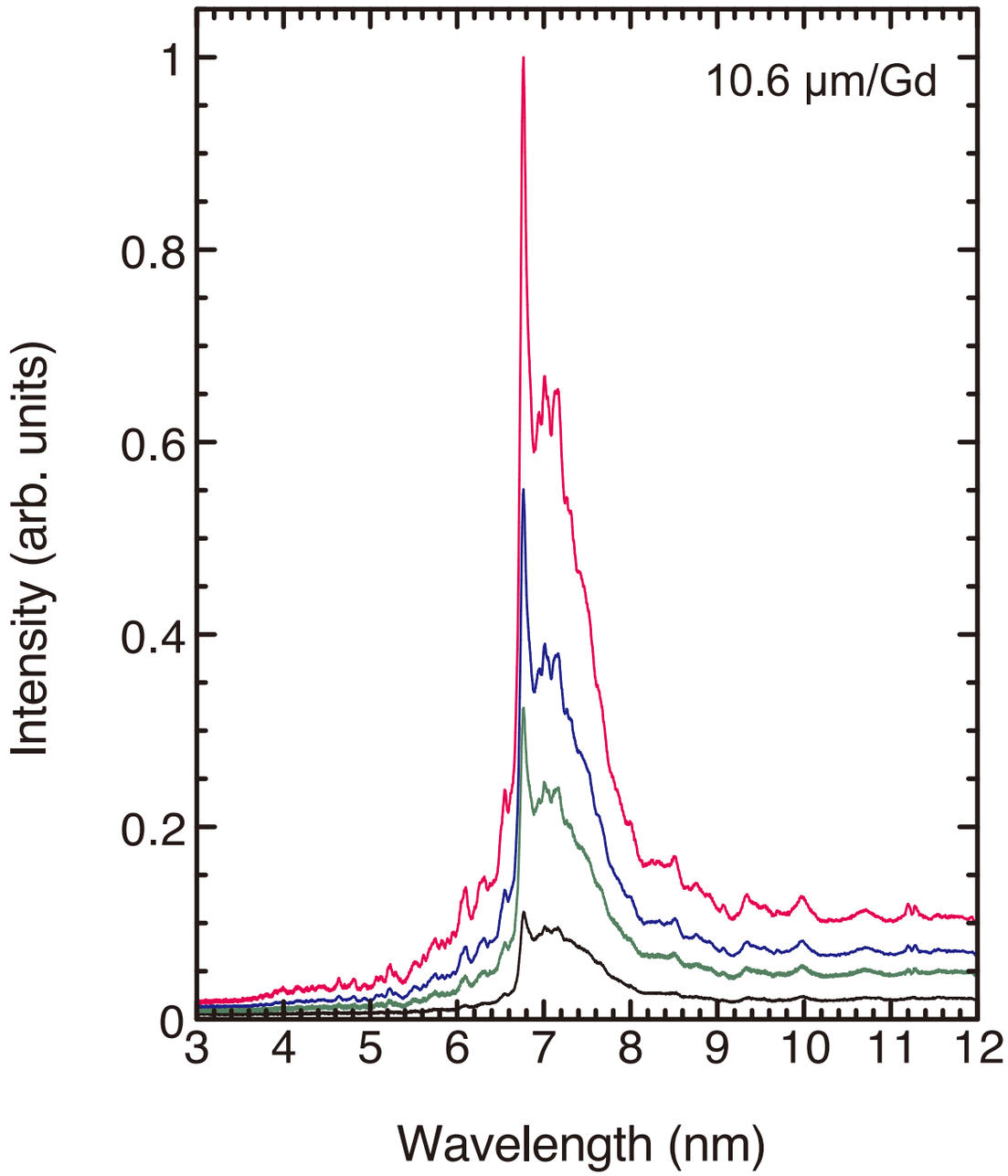
Short laser pulse duration: ~1-2 ns@YAG laser (1064 nm)

Low density targets

Discharge plasmas (low density plasmas)

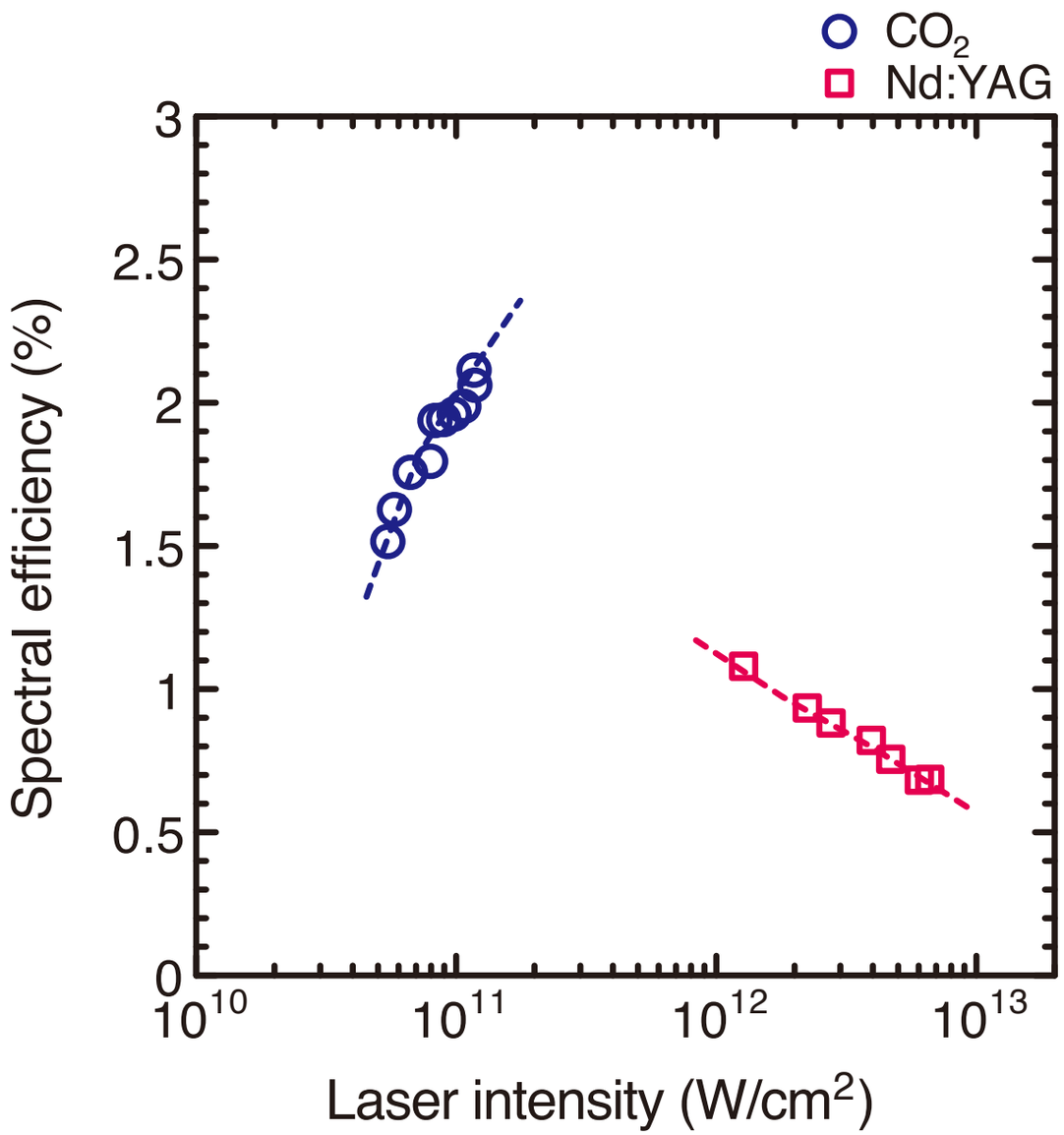
Nd:YAG & CO_2 laser-produced Gd plasmas

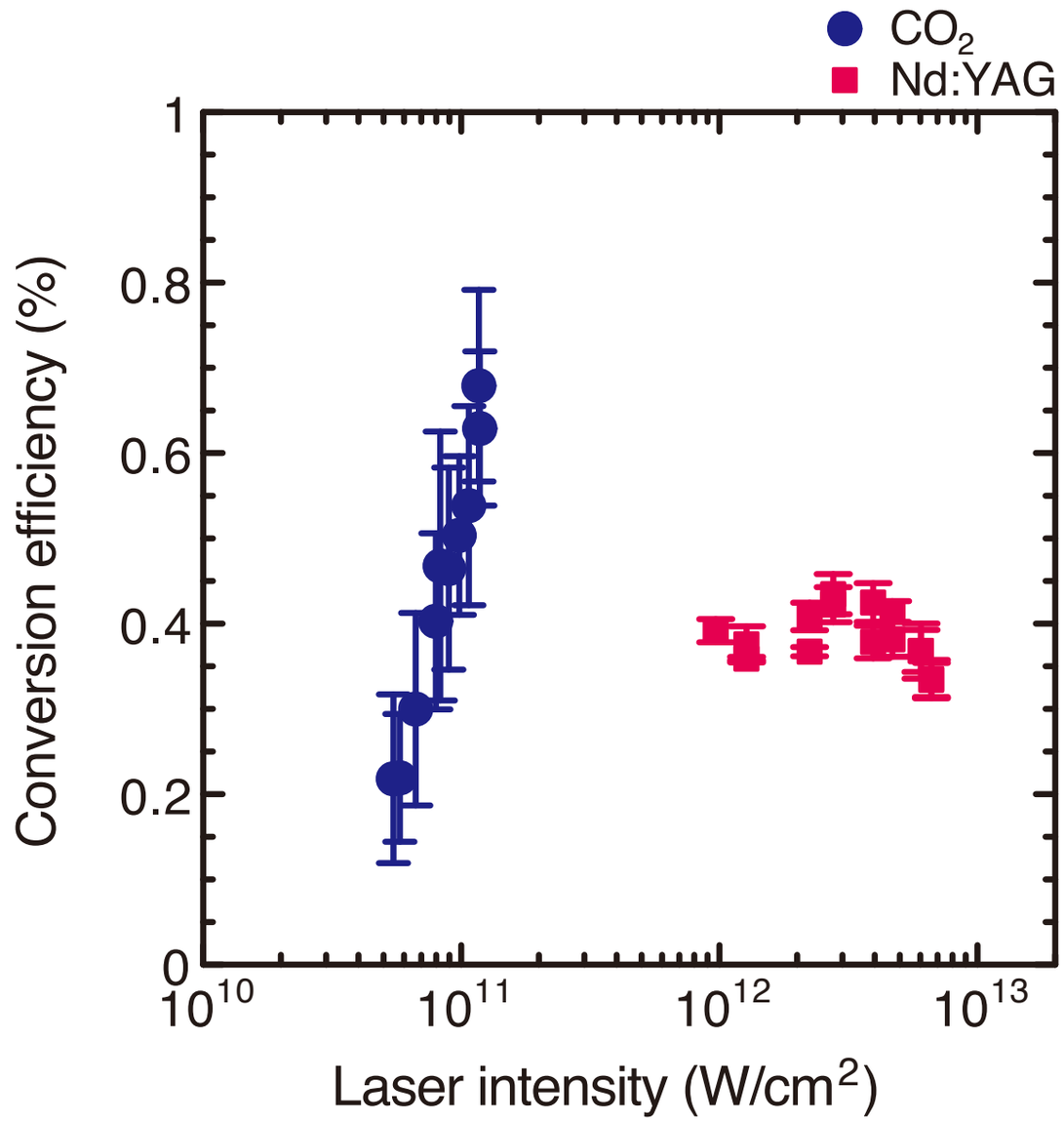




T. Higashiguchi *et al*., **Optics Express** (accepted).

Spectral purity: efficiency in 0.6%BW at 6.x nm

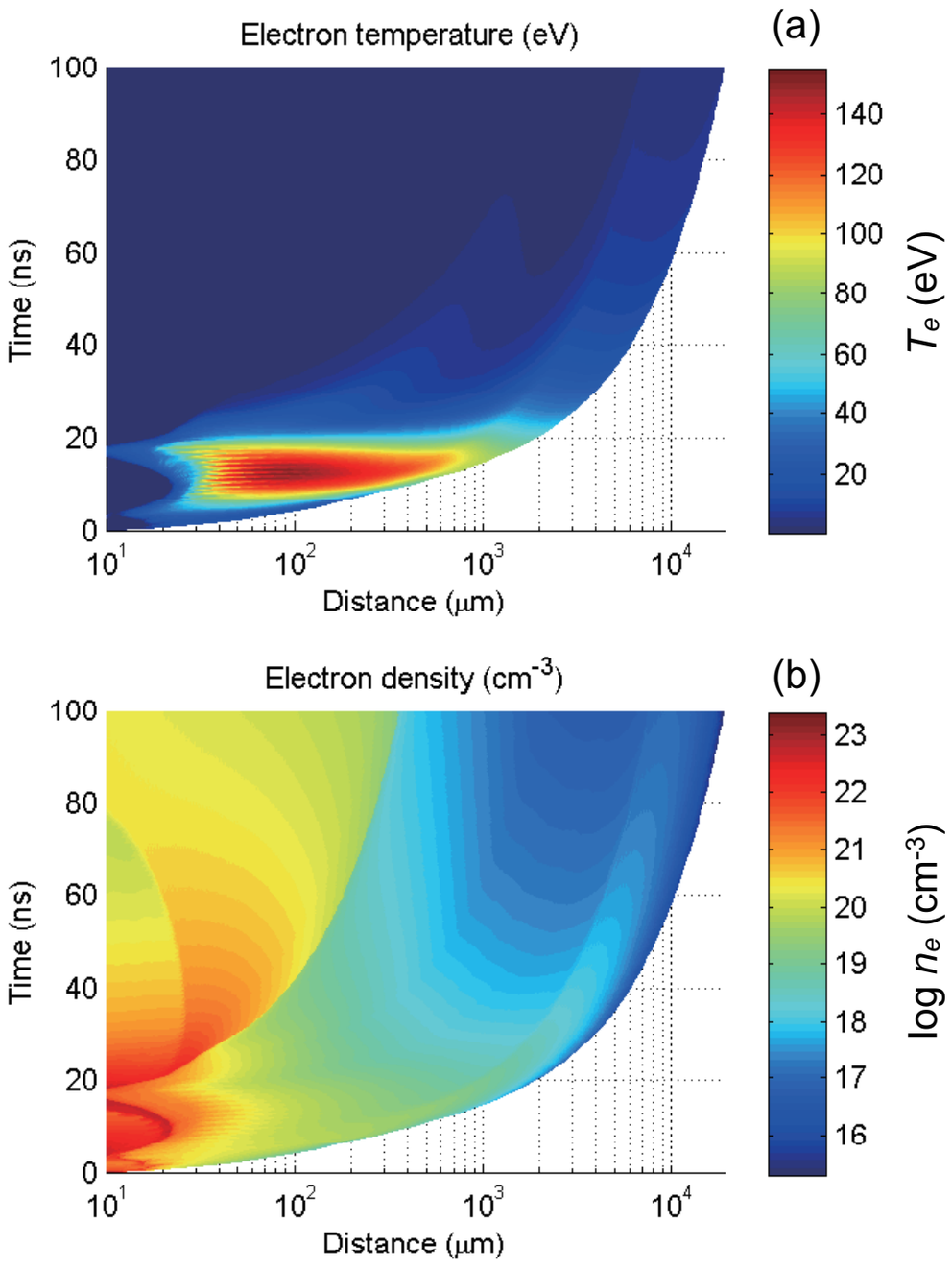




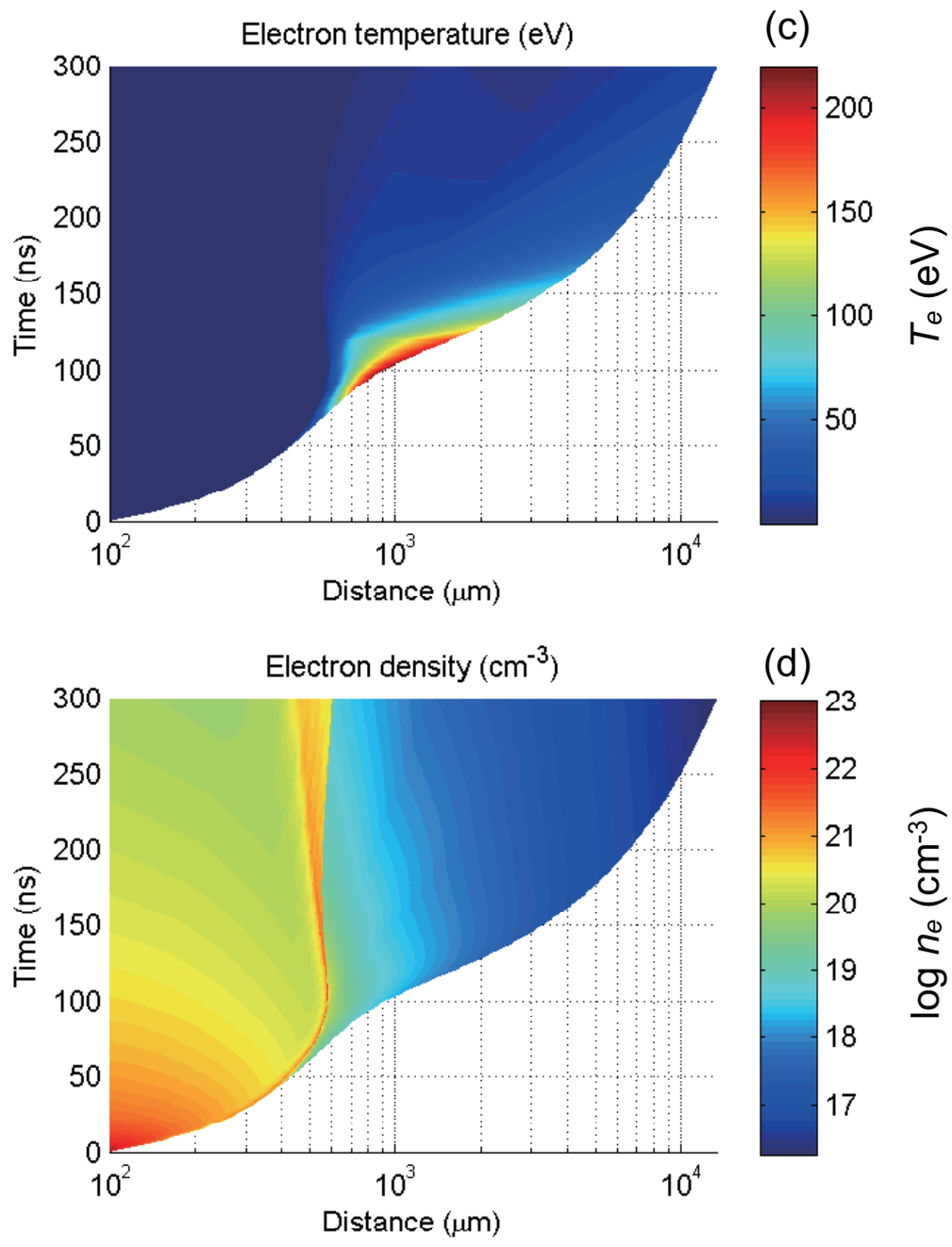
T. Higashiguchi *et al*., **Optics Express** (accepted).

Plasma parameters

Nd:YAG



CO_2

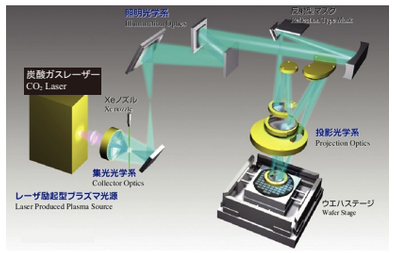


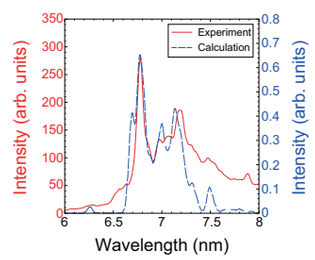
T. Higashiguchi *et al*., **Optics Express** (accepted).

Toward a single shot flash source in WW for Bio Photo **in LAB**

Lithography

EUV & BEUV source study
Wavelength: 13.5 & 6.x nm






半導体容量10倍へ
回路描く光 微細化成功
宇都宮大など
半導体を使った電子部品の小型化に向け、研究を進めていた宇都宮大（宇都宮市）や長岡技術科学大（新潟県長岡市）などのグループが、半導体に回路を描く光の微細化に成功した。彼長が従来の30分の1で、より小さな回路を描くことができる。宇都宮大准教授は「実用化すれば同じサイズの電子部品でも容量が10倍以上になる。スマートフォン（多機能携帯電話）でDVDが見られるほど性能が上がり、コストダウンにもつながる」として

MEXT

キヤノン財団
The Canon Foundation

NEDO

宇都宮大学
UTSUNOMIYA UNIVERSITY

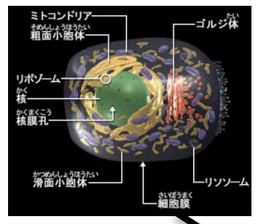
CE ~ 5%

Shorter wavelength

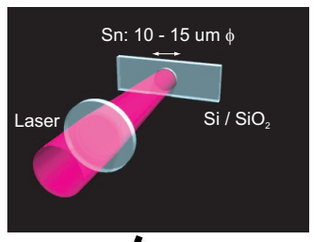
Life Innovation

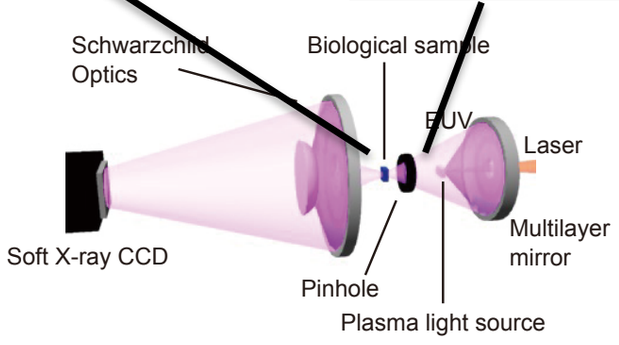
Compact source development for Bio.
Wavelength: 2-4 nm

In vivo cell observation



Original micro source



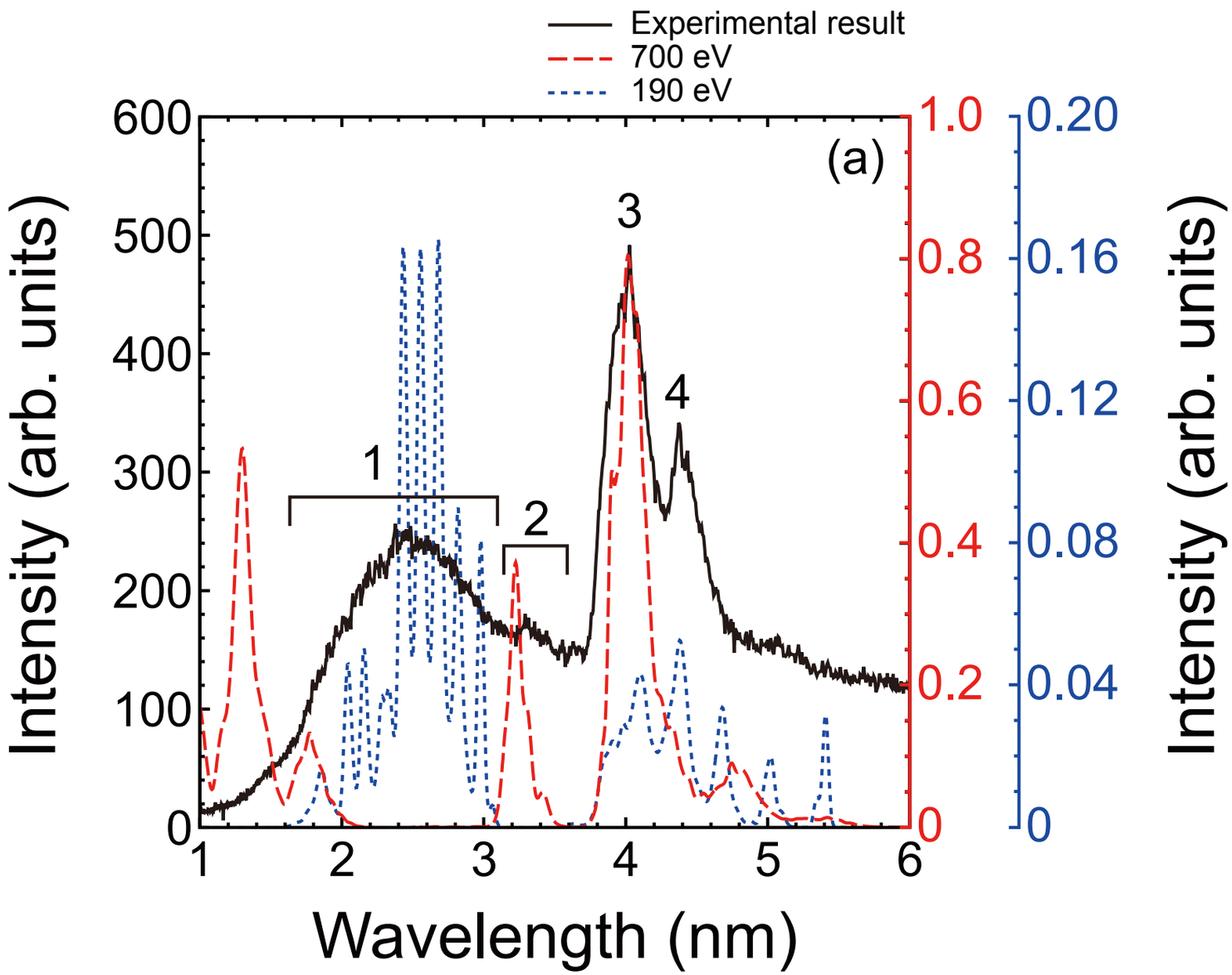


Single shot, flash biological imaging

WW 100-μJ at 100-mJ laser

CE ~ 0.1%, 100 μJ (?)

Low temperature result from Bi by 150-ps laser



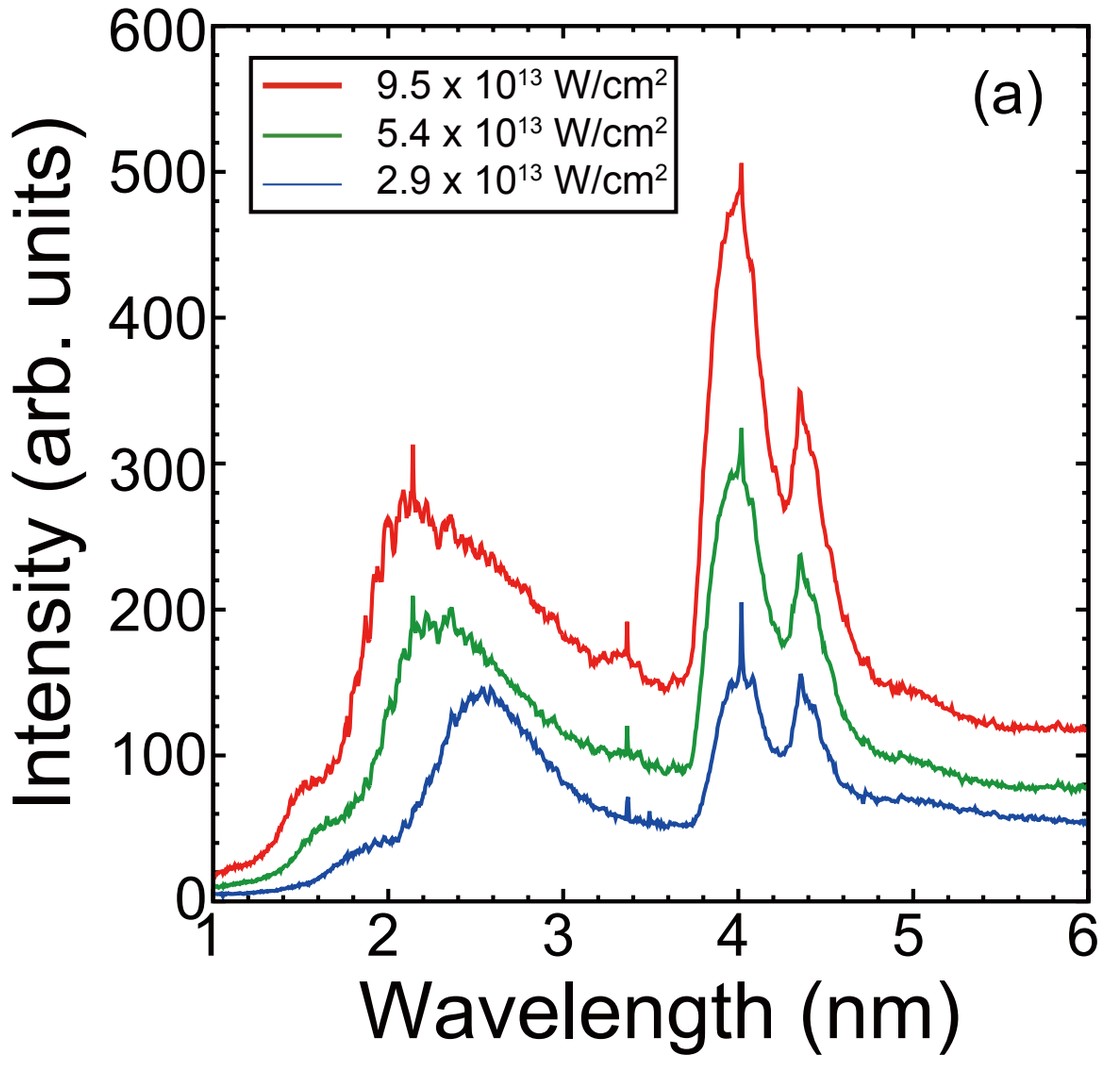
1: 4f-5g, < Bi^{35+}

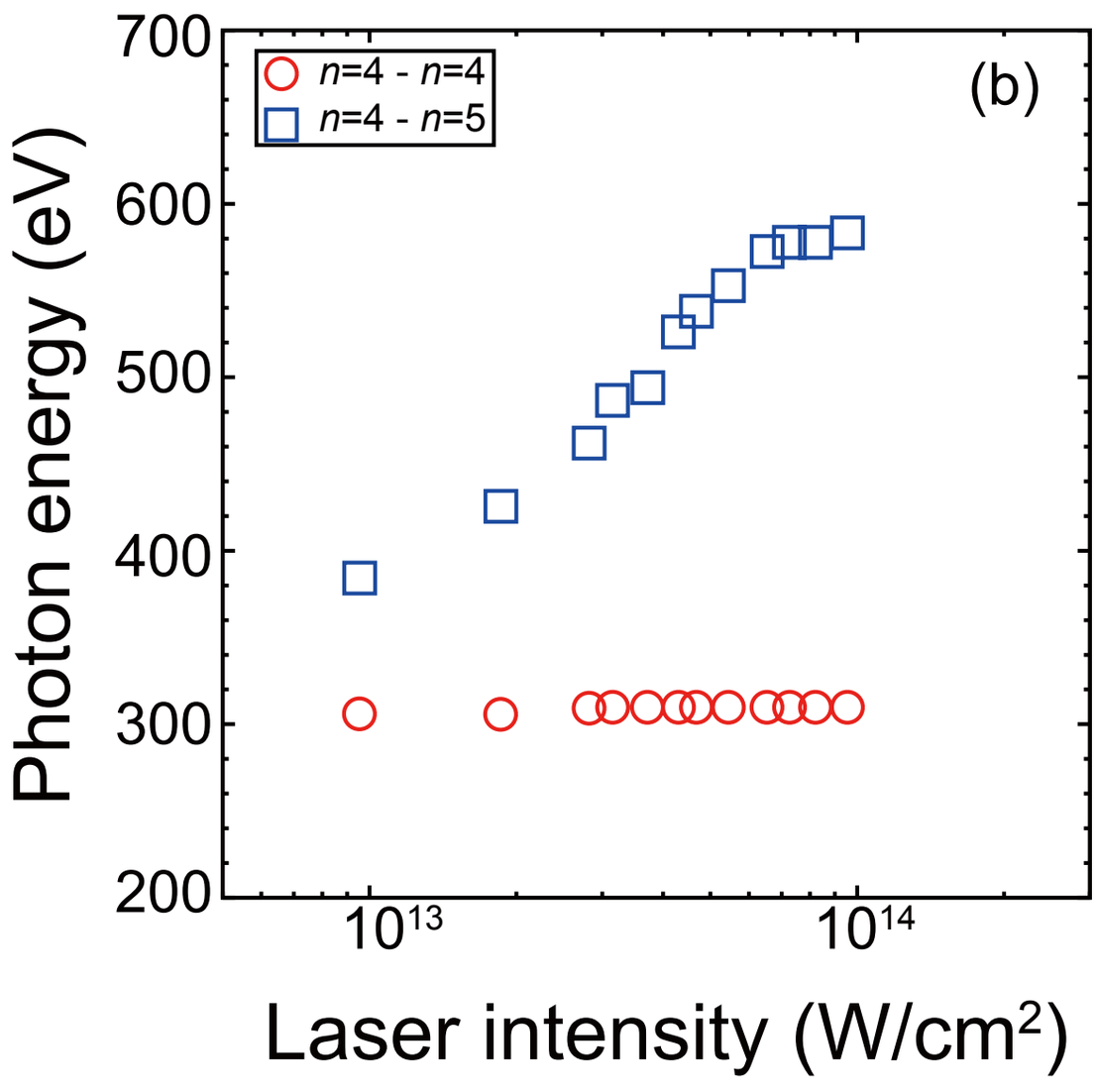
2,3: 4p-4d, 4d-4f, Bi^{36+}-Bi^{45+}

4: 4d-4f

T. Higashiguchi *et al*., Appl. Phys. Lett. **100**, 014103 (2012).

Laser intensity dependence in Bi emission





T. Higashiguchi *et al*., Appl. Phys. Lett. **100**, 014103 (2012).

Concept: Unresolved transition array (**UTA**) many resonant lines

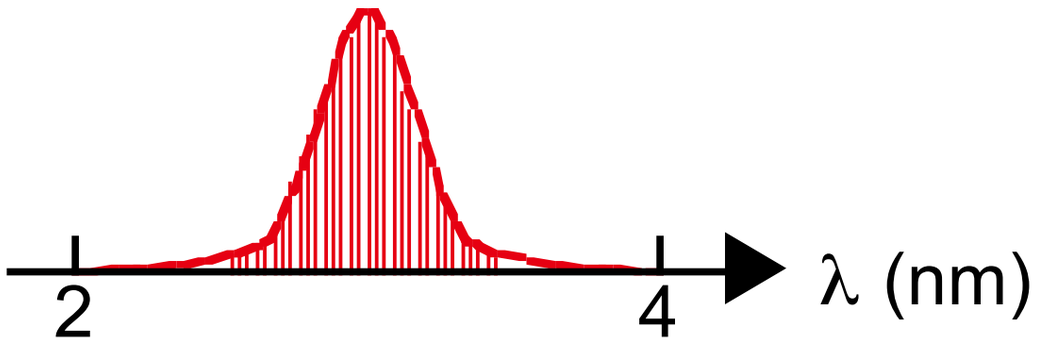
13.5 nm CE ~ 5% by Sn

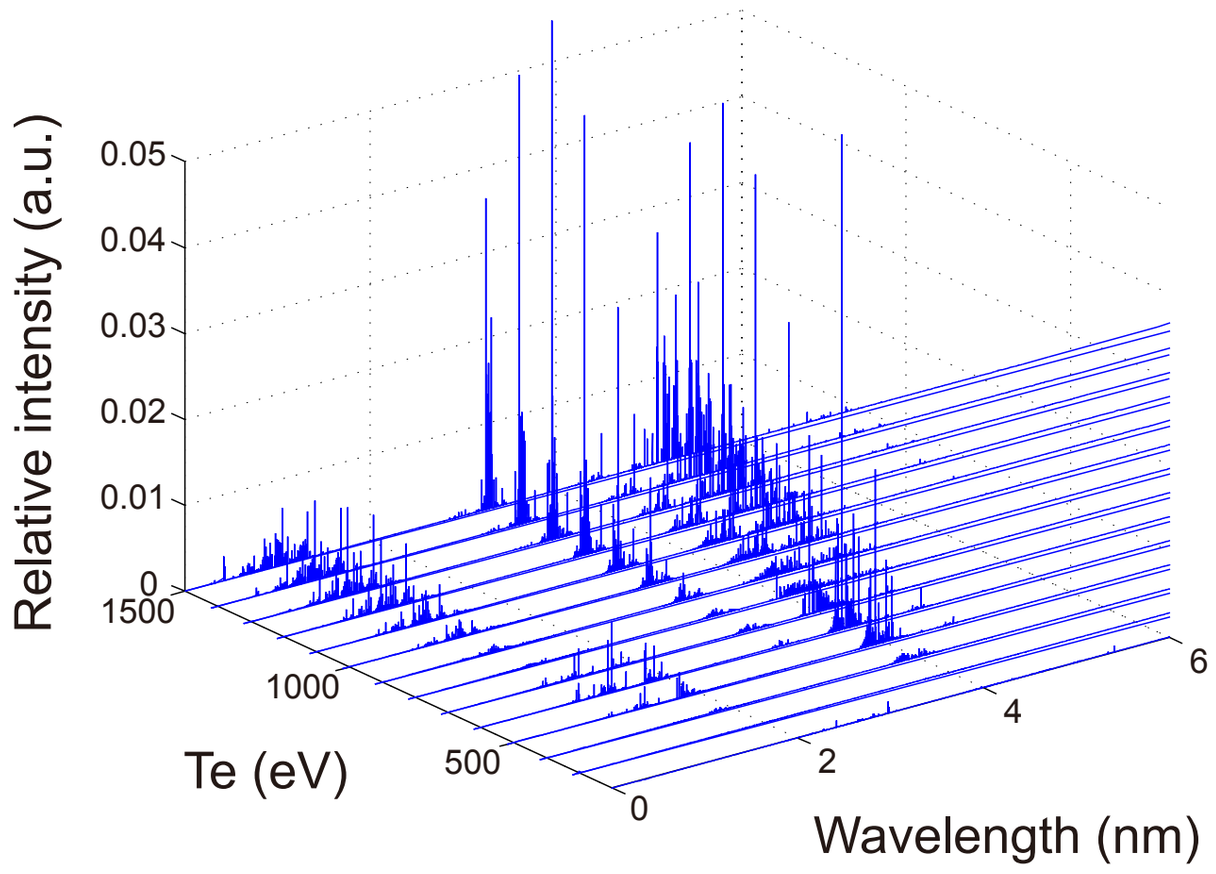
6.x nm CE ~ 1% by Gd/Tb

3 nm and/or 4 nm CE > 0.1% by Bi

(a) Line spectrum

(b) UTA





T. Higashiguchi *et al*., Appl. Phys. Lett. **100**, 014103 (2012).

Extreme Condition: keV Bi plasma spectra

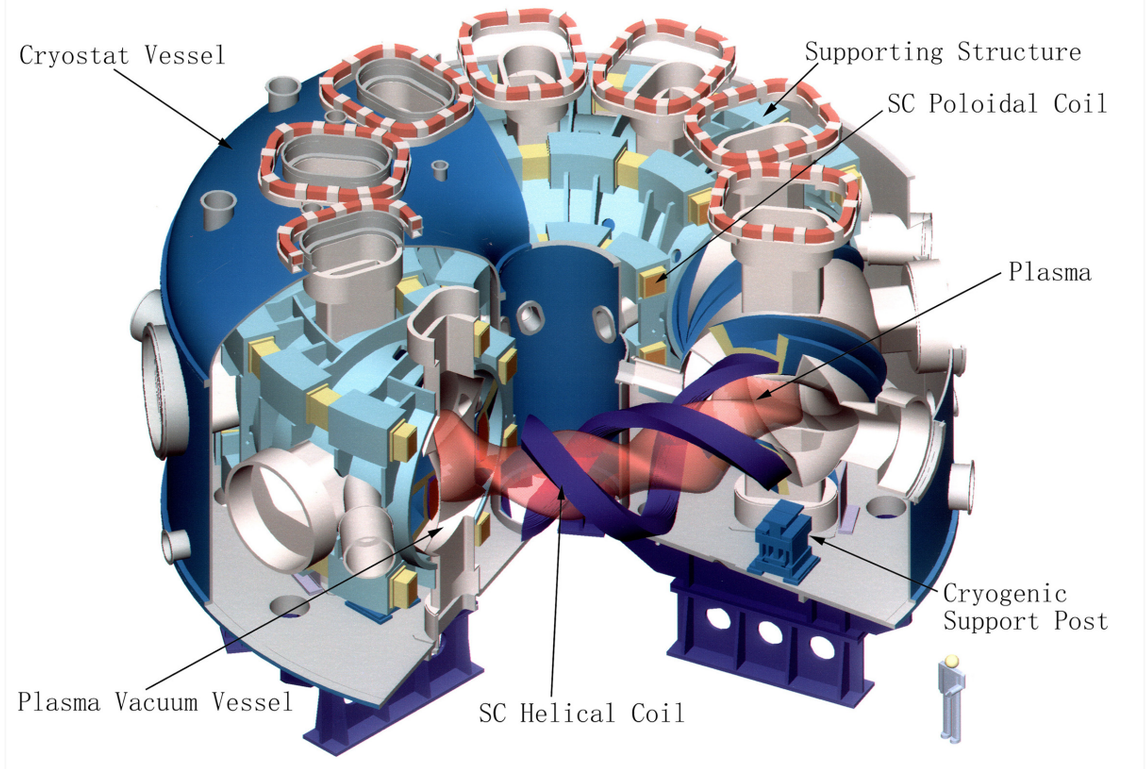
Low density, high temperature 1-keV plasma

optical thin, low density

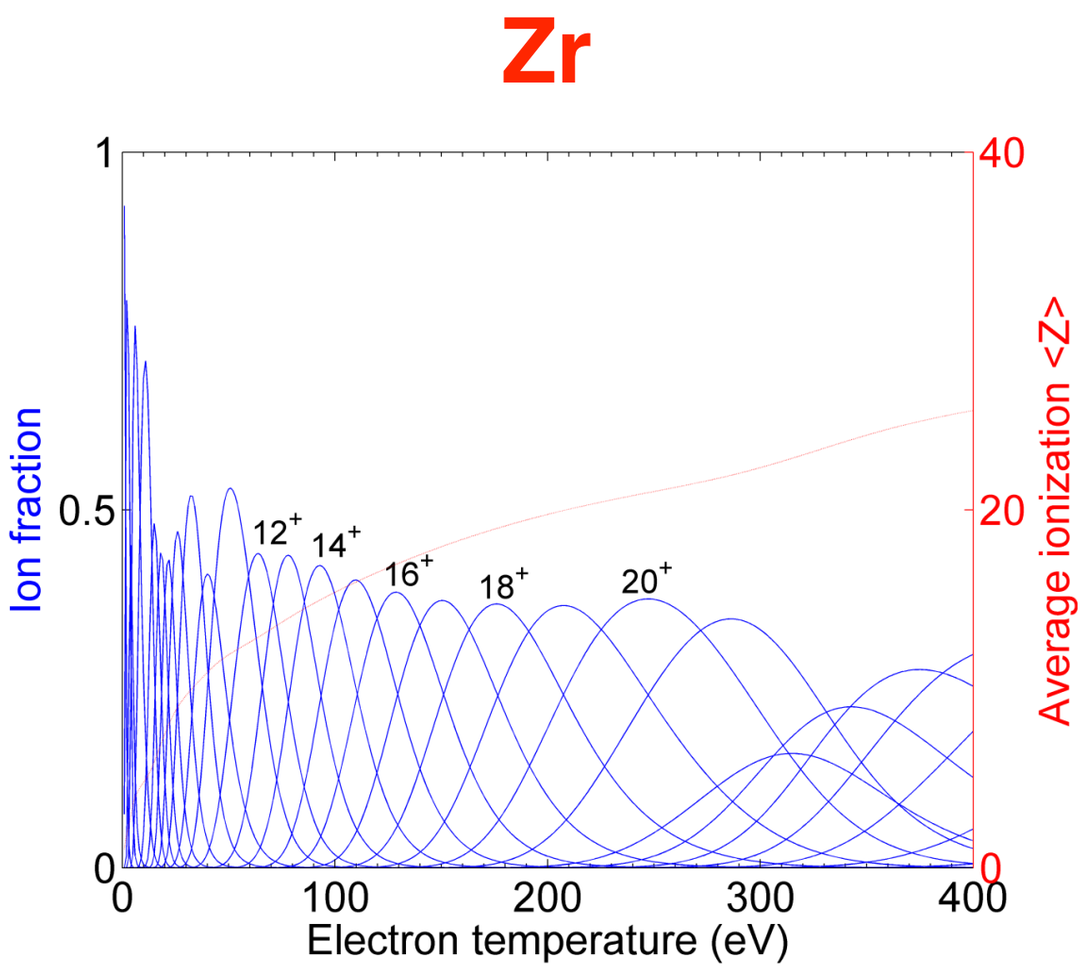
Oct.17 : 30 shots

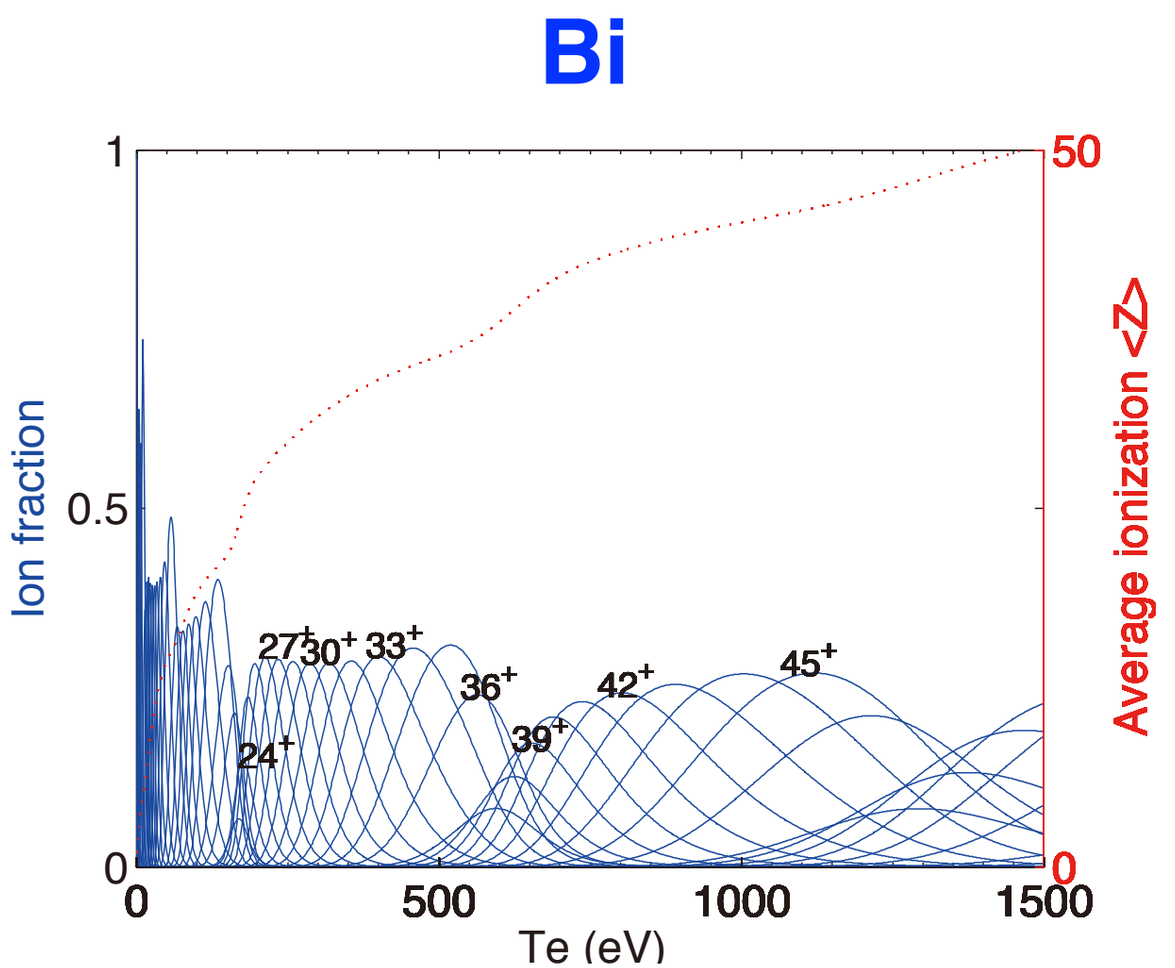
optical thick, high density

May 27 - May 31 : 49 shots



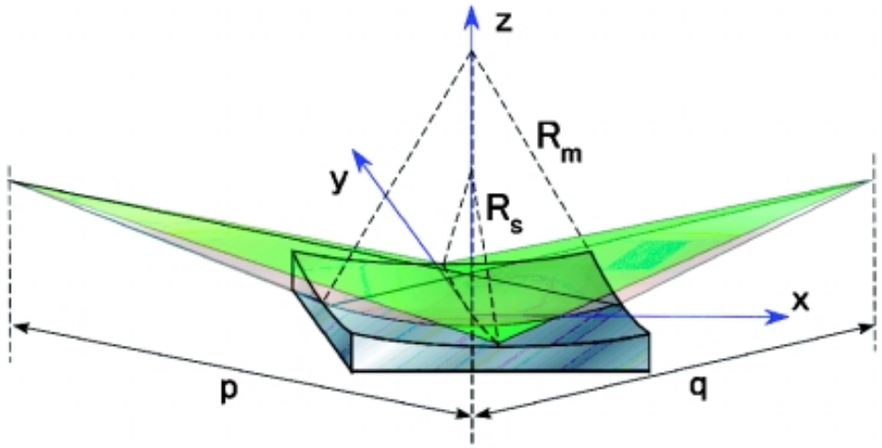
Lower temperature ~**0.2** keV vs 1 keV

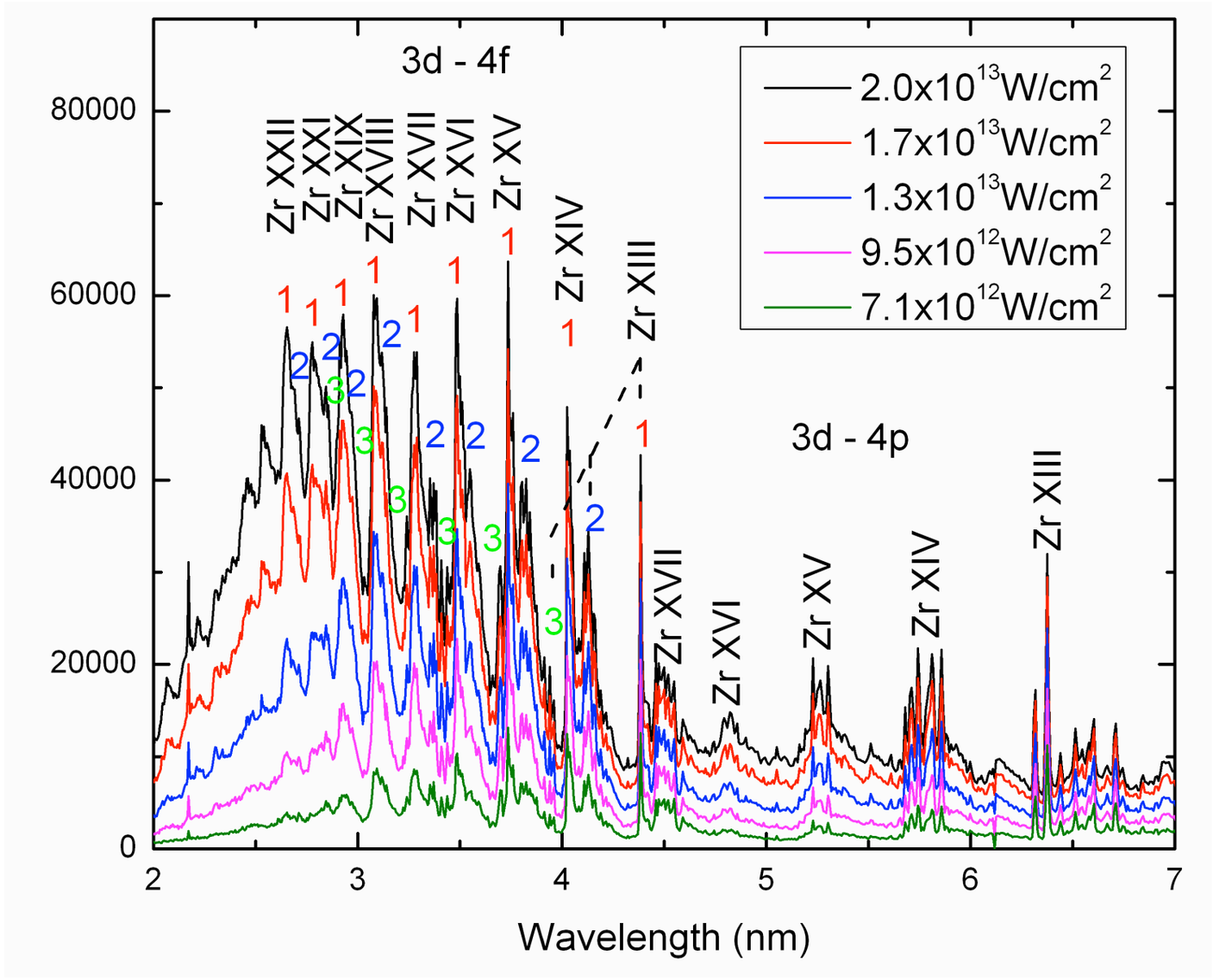


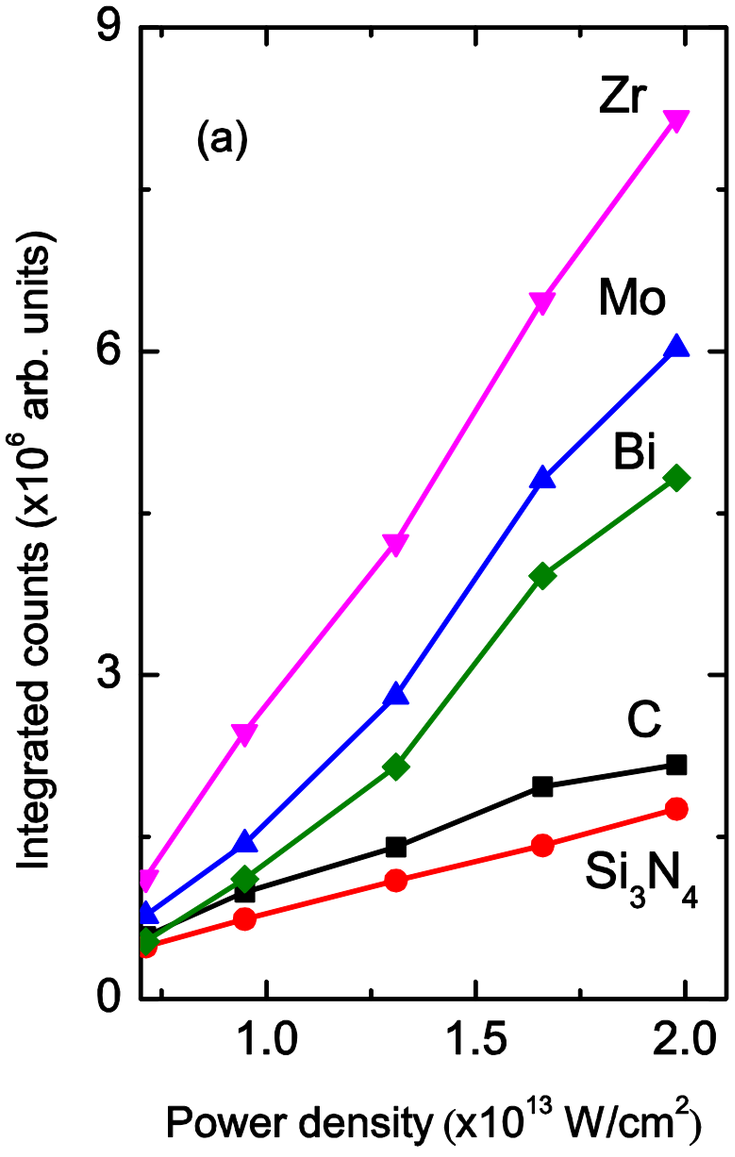


J. Phys. B **45**, 245004 (2012).
Appl. Phys. Lett. **102**, 041117 (2013).

Zr plasma WW source for 1-μm laser







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